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The Symmetrical-Integral Model of Conceptual Change: The Case of Physical and Chemical Thermodynamics

Shimeles Assefa Alemu

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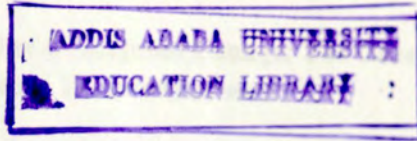
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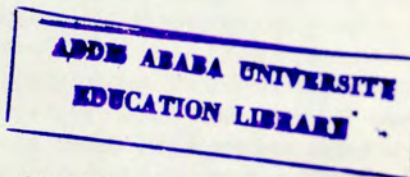
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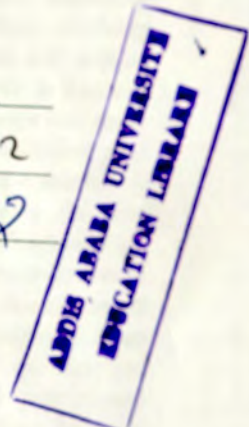
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ABSTRACT

The Symmetrical-Integral Model of Conceptual Change: The Case of Physical and Chemical Thermodynamics

Shimeles Assefa Alemu (for PhD in Curriculum Design and Development)

Addis Ababa University, 2012



The purpose of this study is to develop and test the symmetrical-integral model of conceptual change. Development of Conceptual change models is a growing area of research in science education. A survey of conceptual change research helped me develop a new model of conceptual change which I called 'The Spiral Cognitive-Sociocultural Model of Conceptual Change'. This new conceptual change model was tested on Grade 12 physical thermodynamics and chemical thermodynamics units teaching dressed with my hybrid method of 'Reasoned Persuasive Collaboration' from a class of Critical Analytic Pedagogies. This model, unlike previous models requires change in both rational/knowledge and extra rational or motivation, affection, and other socio-cultural factors. This model is, therefore, comprehensive and produces the whole child, unlike previous models which produce cognitive child only by focusing on knowledge change alone. The model unifies personal construction of knowledge with social construction of knowledge along the axis of learning. The cone of learning in SCSMCC shows that there is no primacy of either the personal or the social construction of concepts and by advocating the balanced-symmetrical approach to learning my model rejects asymmetry from both the personal and socio-cultural sides of theories of learning. The model, therefore, resolves a long standing debate of whether knowledge or concept formation is the result of pure rationalism or pure empiricism. In modern learning theories terms, is knowledge the result of pure cognition or pure socio-culturalism? The holistic model shows that it is the synergy of both and neither personal cognition nor socio-culturalism is effective when taken alone. The guiding philosophy for my research is functional monism and whose epistemology, ontology and methodology are defined to fit the context of the SCSMCC as integrated model. Ontologically, knowledge is defined as a process that is spirally in transit between individuals and the society. There is no inside and outside duality or two important points which are not functionally unified, one point inside the mind and another point external to it, namely inside the society. The process has neither inside nor outside as it is not made up of points. Epistemologically, I defined the process of knowledge generation as a synergy of rationalism and empiricism. Methodologically, inquiry should be carefully balanced, integrated and meticulously planned spirally alternating between individual critical thinking involving reflections and group/social persuasion during collaboration. This philosophy of education will help us make accurate curricular decisions. According to this holistic model the curriculum needs to balance both personal and social development. To test the validity of this model a mixed methods design was used. The dominant quantitative part uses the quasi-experimental design and the supportive qualitative part uses documentary analysis, interviews, and classroom observations. This research produced a number of key findings: in both physical thermodynamics and chemical thermodynamics treatments the new conceptual change approach is significantly better than the traditional transmission of information in bringing about deep conceptual understanding and students learned thermodynamics better by the integrated model of conceptual change; the new model empowered female students and enhanced the magnitude of performance of low achievers. The experimental variables have predicted deep understanding of thermodynamics by showing medium to large effects (29.2% on the average) on achievement tests. Conceptual understanding showed constant and large effect sizes (0.78 for physics and 0.77 for chemistry). The magnitude of knowledge and extra rational constructs transfer from physical thermodynamics to chemical thermodynamics is relatively quite good. This shows that the new model is better than models based on either pure cognition or pure socio-culturalism in which knowledge transfer

is very difficult, if not impossible. The knowledge transfer part of the research is used to overcome fragmentation of knowledge because of context dependence and integrate knowledge of thermodynamics in different situations while at the same time applying abstract cognitive concepts in different concrete situations. This proposed model of transfer shows that abstract principles or schemata which are context-independent can be effectively applied to similar situations when mediated by context-sensitive knowledge. The transfer is tested between two similar situations in school setting which paves the way for transfer between classroom and real world situations. The current so-called constructive curriculum for secondary schools needs to be revised as some methods employed are traditional, namely, lectures, gapped lectures, and demonstrations. The curriculum is also not explicit about which kind of constructivism it uses, namely radical or social constructivism. Conceptual change strategies were not shown in the new curriculum. Concepts related to the first law of thermodynamics and enthalpy were most difficult for students. Author-induced misconceptions were detected in illustrations, equations and descriptions of unit one of Grade 12 physics and unit three of Grade 12 chemistry. Procedural knowledge and conceptual knowledge were not well balanced, connected (integrated) and sequenced in the new curriculum. The main conclusions drawn from this research are that current teaching approaches need to be replaced by the new conceptual change approach which is experimentally tested to be effective in teaching science subjects. The curriculum needs to be replaced by concept-based curriculum which focuses on in depth teaching of basic and core concepts of science in order to cope with knowledge explosion and syllabus coverage. The curriculum development process should use both top-down and bottom-up approaches. The specialist knowledge should be supported and approved by public and other stakeholders. The new model needs to be tested in other knowledge domains as the findings suggest that it is context invariant and stable overtime regarding conceptual understanding ($d=0.78$ for physics and $d=0.77$ for chemistry) and prediction of complete understanding ($R^2_{\text{adjusted}}=29\%$ for physics and 29.4% for chemistry).

DEDICATION

To My Late Brother Ermias Assefa Alemu

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ACRONYMS AND SYMBOLS

Acronyms

ADL	Actual Development Level
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
CAMCC	Cognitive-Affective Model of Conceptual Change
CAP	Critical Analytic Pedagogy
CG	Curriculum Guide
CR	Collaborative Reasoning or Conceptual Restructuring; Depending on Context
CRKM	Cognitive Reconstruction of Knowledge Model
CTAT	Chemical Thermodynamics Achievement Test
df	degrees of freedom
DU	Deep Understanding
EDA	Exploratory Data Analysis
ETP	Education and Training Policy
GLM	General Linear Model
HA	High Achiever
HSD	Honestly Significant Difference
ICR	Individual Critical Reflection
IPT	Initial Personal Thinking
KE	Kinetic Energy
KSC	Knowledge Structure Coherence
LA	Low Achiever
LSQ	Learning Strategies Questionnaire
MA	Medium Achiever
MANOVA	Multivariate Analysis of Variance
MoE	Ministry of Education
MS	Mean Squares
OMCC	Orthodox Model of Conceptual Change
PE	Potential Energy
PP	Persuasive Pedagogy
PTAT	Physical Thermodynamics Achievement Test
RPC	Reasoned Persuasive Collaboration
SAI-II	Science Attitude Inventory-II
SCSMCC	Spiral Cognitive-Sociocultural Model of Conceptual Change
SD	Standard Deviation
SEB	Standard Error of Unstandardized Coefficient
SMQ	Science Motivation Questionnaire
SPSS	Statistical Package for Social Sciences
SS	Sum-of-Squares
SSI	Study Skills Inventory
TG	Teacher's Guide
TLD	Traditional Lecture-Demonstration Method
ZPD	Zone of Proximal Development

Symbols

α	Significance Level
B	Un-standardized Coefficient
β	Standardized Coefficient
C	Comparison
d	Effect Size or Differential; depending on context of use
Δ	Delta
η	Eta
E	Experimental
F	F statistic
G	Gibbs Free Energy
H	Enthalpy
$\int$	Integration Sign
M	Mean
n	Sample Size or Concentration; depending on context of use
N	Non-randomness
O	Observation
P	Calculated Significance (sig.) or Pressure; depending on context of use
Q	Heat
r	Correlation Coefficient
R	Multiple Correlation Coefficient or Universal Gas Constant; depending on context
S	Entropy or Student; depending on context of use
t	t statistic
T	Temperature or Test; depending on context of use
U or E	Internal Energy; depending on the preference of text book authors of grade 12
V	Volume
W	Work
X	Treatment

CHAPTER ONE: INTRODUCTION

1.1 Introduction

In this chapter, I will try to discuss the background that led to the development of the SCSMCC as an integrated model of conceptual change. The purpose of the current study, the statement of the problem, theoretical and conceptual frameworks of the study, significance of the study, and organization of the manuscript are all discussed in this chapter. My integrated conceptual change model which I called SCSMCC (Spiral Cognitive-Sociocultural Model of Conceptual Change) requires all extra rational constructs change, in addition to, conceptual change (Shimeles, 2012). This model, unlike previous models requires change in both rational/knowledge and extra rational or motivation, affection, and socio-cultural factors. This model is, therefore, comprehensive and produces the whole child, unlike previous models which produce cognitive child only by focusing on knowledge change alone. The model unifies personal construction of knowledge with social construction of knowledge along the axis of learning depicted in Figure 1.1. The six phases of my new model are shown in this chapter along with an example lesson plan. In addition, limitations, delimitations and conclusions are all presented in this chapter.

1.2 Back Ground of the Study

In the preceding years contrary to intentions of Ethiopian Training and Education Policy (ETP, 1994), the science curriculum of Ethiopia did not emphasize knowledge construction by the learners as most of the teaching –learning in both the plasma TV and non-plasma TV cases were practicing most of the time lecture-demonstration (MOE Curriculum Guide, 2005; Plasma Manual and Guide, 2005) which is a teacher-centered method. In the school where I did my research, however, plasma TV classes were not conducted in the academic year 2010/2011 and a new curriculum which appears to be constructivist and which was not properly implemented is introduced as I started my treatment of conceptual change and knowledge transfer. The teachers were not given on-the-job training to implement the new curriculum. The use of conceptual change models is so far unknown in Ethiopian science education. Learning does not occur by transmitting information from the teacher or the text book to the learner's brain. Students are viewed as "blank slates" on to which information is etched by the teacher. I believe that the current practice of science education is not suitable for science learning as it is using lecture- recitation teaching method especially in secondary schools. Students taught using this traditional transmission strategies may not achieve deeper conceptual understanding and, therefore, lack sufficient problem solving skills to alleviate/solve the many problems of our nation. Teachers must be trained well enough in pedagogical techniques as well as in content knowledge in order to implement the existing so-called constructivist curriculum effectively.

Conceptual understanding underlies all known problem solving skills, decision making, and innovation which are the ultimate goals of any educational system. Conceptual change research and instruction were basically started to tackle problems of conceptual understanding and related lack of problem solving skills in physics education. Later on research in conceptual change has gone beyond physics to include other science subjects such as chemistry and biology. These days research in conceptual change has almost become domain general, including subjects such as mathematics, psychology, and history. The current educational system of Ethiopia did not bear the fruit of (as many studies have shown: MOE, ESDP III, 2005; Amare, 2009) solving the many problems of the nation. That 'educated' persons lack good decision making capacities and lack of innovation in the fields of technology is all the results of lack of conceptual understandings and process skills in the basic sciences such as physics and chemistry. Therefore, our traditional curriculum did not result in deeper conceptual understandings and it is high time that we try an alternative curriculum, especially for the basic sciences as teachers are more commonly concerned about coverage of syllabus/course than teaching for deeper conceptual understandings (Amare, 2009:416). Ashebir (2009) showed that students in Dire Dawa preparatory schools lack conceptual understandings of basic concepts of calculus and the traditional teaching lacked a balance between procedural and conceptual understandings.

Pintrich and associates (1993) in their criticisms of Posner and associates (1982) classical model of conceptual change, set the theoretical landscape as to what the future models of conceptual change should look like. Based on their suggestions, Dole and Sinatra (1998) developed their "Cognitive Reconstruction of Knowledge Model" (CRKM). Their model used motivational constructs for the purpose of facilitating knowledge change but did not require motivational constructs change themselves. Similarly, Gregoire (2003) developed her "Cognitive-Affective Model of Conceptual Change" (CAMCC). Her model added affective factors, in addition to motivational factors to facilitate conceptual change but did not require the extra rational or "hot" constructs themselves to change. Posner and associates (1982) developed the first model of conceptual change. These researchers based their model on Kuhn's (1962) famous book on theory change and the works of cognitive developmental psychologists such as Piaget's assimilation, accommodation, and equilibration. Pintrich and associates (1993) called the classical model a "cold" model of conceptual change for it doesn't include motivational factors and focus only on cognitive factors. For nearly two decades this model guided research on conceptual change. Dole and Sinatra (1998) came up with a "warm" model of conceptual change which included motivational factors in addition to cognitive factors. They raised the temperature of their model to escape Pintrich and associates (1993) criticism of the "cold" model of conceptual change. Gregoire (2003) also came up with a model of conceptual change by further increasing the temperature which she claimed to be a "hot" model of

conceptual change. She added affective factors in addition to cognitive and motivational factors to her model.

Murphy (2007) also came up with a model of knowledge and belief change. She claimed, in addition to model development, that the age old debate about the source and location of knowledge should be resolved by minimizing the gap between the cognitive and the situative/socio-cultural banks of the theoretical metaphoric river. To decrease the gap a bridge needs to be built between the two river banks and this is the only way forward in conceptual change research and conceptual development should be based on interplay of both the individual and socio-cultural/situative factors. However, she did not elaborate on the nature of the bridge that should be built. Patricia (2007) doubted Murphy's proposal by saying that '*bridging cognition and scioculturalism within conceptual change research: unnecessary foray or unachievable feat*'. She said that the two sides of the metaphoric theoretical river are so extreme that they cannot be bridged. Vosniadou (2007) has similar idea as that of Murphy (2007) in which she claimed that there is no way forward except to bridge the two extremes in the future for conceptual change research.

Based on the above mentioned ongoing debates, I tried to fill the gap in conceptual change research by developing my proposed integrated model of conceptual change which I called the '**Spiral Cognitive-Sociocultural Model of Conceptual Change (SCSMCC)**'. To implement this model in the science classroom, I used the **Critical-Analytic Pedagogies (CAPs)** proposed by Murphy (2007) for such kind of research. Two of the CAPs strategies for conceptual change research she mentioned were 'Persuasive Pedagogy' (PP) and 'Collaborative Reasoning' (CR) and she claimed that these methods are empirically tested and proven fruitful. I integrated these two methods and developed a hybrid method to use the synergetic effect of using combined methods. I called my method '**Reasoned Persuasive Collaboration (RPC)**' which I used in the teaching of topics found in secondary school physics and chemistry. The literature shows that there is no comprehensive model of conceptual change, my selected and developed model is based on recent research works in the area of conceptual change and which is hitherto not experimentally tested but implied useful as the way forward in the conceptual change research.

There is the debate "whether knowledge is to be looked upon as personal and residing within the individual or if it is embraced within discursive practices and cultural tools" (Hallden, et al, 2007:38). Socio-culturalism puts knowledge within the immediate social context and human interactions (example, Social constructivism) and gives primacy to socio-cultural interactions. Cognitivism gives primacy to the individual mind as both the constructor of knowledge and its repository (example, radical constructivism).

In socio-culturalism “knowledge” is viewed as **between** rather than **within** individuals, with conceptual understanding and conceptual growth portrayed as functions “accomplished by activity systems and communities of practice” (Greeno and Van de Sande, 2007). The bridge that connects the individual to the social construction of knowledge must be built. That is the bridge that eventually connects the cognitive and socio-cultural sides of the epistemological debate. In the bridging process, I start with individual critical and analytic thinking and move towards sharing of what is critically thought and analyzed; and spirally rethink again individually which leads to still another higher sets of sharing knowledge; the process goes on upwards on knowledge accumulation and application ladder of the spiral with increasing depth (vertical transfer) and breadth (horizontal transfer) which leads to more adaptive expertise.

Research in science education is in its infancy in Ethiopia and studies in this field need to address the problem of lack of conceptual understanding and conceptual change. This study therefore tries to test a conceptual change model that may have far reaching implications for science curriculum design and development. And thereby alleviate the various misconceptions creeping into students minds as a result of the practice of the traditional content loaded science curriculum and instruction or the existing so-called constructivist curriculum. The conceptual change model which can be tested by this research treats the big/major concepts and identifies the misconceptions students have and properly address them so that students get clear ideas about the established scientific conceptions. By reducing the content load and integrating them with science process in the instructional transaction we can engage learners in the tasks and complete the treatments according to the school schedule. For this purpose one of the most misconceived topics in Chemistry and Physics is used, namely, “Heat and Thermodynamics”. The results obtained for unit one of Grade 12 Physics “Physical Thermodynamics” and unit three of Grade 12 Chemistry “Chemical Thermodynamics” are checked for conceptual change and also the test results are compared for the subjects to see if transfer of learning has taken place from Physics to Chemistry in the time interval of one month between the teaching of the two units. The results obtained from the study suggest that the SCSMCC and the RPC strategy used to test the model are very much fruitful for teaching the sciences. The study finally suggests the implications of the SCSMCC as integrated model of conceptual change for secondary science curriculum design and development. The status of current science curriculum was explored to see whether it is the right kind of curriculum for our secondary schools and address the issue of conceptual change.

1.3 The Purpose of the Study

This research tries to test my proposed model of conceptual change which is depicted in Figure 1.1. Several attempts have been made to come up with a comprehensive and original model of conceptual change. This comprehensive and new model has been developed using extensive literature survey of conceptual change research. My SCSMCC as integrated model which I consider a “hot” model not only incorporates conceptual change but also includes changes in motivation, attitude, perceptions(beliefs) about socio-cultural context. The process of knowledge generation is modeled as interplay between cognitive and socio-cultural factors. Many authors suggested such an interplay as a future for conceptual change learning while very few of them considered such bridging as a futile attempt because the two categories are so extreme. I personally believe and agree that a synergy of the two categories of learning theories is possible and the only way forward in conceptual change learning. What makes my research work and thus my model original is that many of the researchers which suggested that a bridge can be built between the two river banks of the metaphoric theoretical river never conceptualized the type of bridge in unifying the cognitive perspectives and the socio-cultural perspectives. The spiral inside the conical helix continually touching the cognitive and the socio-cultural axes creating a series of nodes and revolving about the central axis of learning is one such conceptualization of the bridge. The spiral is simply the geometrical embodiment of the interplay suggested by many researchers of conceptual change between the two categories of theoretical perspectives. And hence the spiral serves as a bridge between these two categories of theoretical perspectives. The model also provided its six phases of each cycle of the spiral and the way it is applied both inside the classroom and outside the classroom. The six phases of SCSMCC model dressed with the method of ‘Reasoned Persuasive Collaboration’ (RPC) are illustrated with an example from thermodynamics. If in one cycle (the initial cycle) conceptual change is not achieved in the classroom, similar cycles can be initiated outside the classroom to achieve it. The study also assesses the current status of secondary science curriculum and forwards some suggestions for implications of SCSMCC for curriculum design and development.

The major reason for doing this conceptual understanding research in the sciences is that students usually concentrate on quantitative problem solving of chug and plug type without understanding the qualitative meanings of ideas or concepts behind and usually lack problem solving skills which are transferable to real-world contexts. Our students lack higher order thinking skills and metacognitive skills that are required for problem solving, decision making, and innovation. The general situation in the country confirms that the old conventional science curriculum we are so far using did not produce the kind of human resource that solves the many problems of the nation. Therefore, it became a necessity to try to

develop and test a conceptual change model that demands higher order thinking skills or metacognitive skills especially metacognitive control skills our students are lacking (Shimeles, 2010).

The purpose of this study is, therefore, to develop and test the SCSMCC conceptual understanding model using one of the CAPs strategies which I called 'Reasoned Persuasive Collaboration (RPC)' by way of checking its effectiveness in comparison with Traditional Lecture-Demonstration (TLD) method. The study also checks changes in attitude, motivation, perceptions about instructional strategies, and study skills in addition to changes in concepts of students.

1.4 The Statement of the Problem

The traditional design of curriculum emphasizes the lower cognitive levels and we are still in this type of curriculum because of the resistance of teachers to accept the so-called constructivist curriculum which utilizes both constructivist and traditional strategies. This curriculum design must be changed if we want to raise our educational standards. "We cover more content at the expense of depth of treatment and which is typical attribute of the traditional content-loaded curriculum. This coverage pressure reduces the amount of time available for students to solve problems and think beyond the facts and thus understand concepts" (Amare, 2009: 429). We are teaching our students lower order thinking skills in that we want them to recall and recognize facts and theories. "A type of curriculum that emphasizes the use of knowledge in the context of recall as an end in itself instead of a means for understanding, analysis, synthesis, reasoning, acting and being, ultimately produces people who have inflated self-images but who actually are incapable of adapting to or changing their environment"(Amare, 2009:429). It also encourages didactic lecture formats rather than active student learning. The traditional design is found to be resulting in many misconceptions related to the key concepts that frame the knowledge of a discipline (Erickson, 1998). Students have a fragile grasp of many key concepts in science and mathematics (ibid.). According to Perkins (1992), students learning by the traditional approach failed to transfer their textbook science problem- solving to real world contexts where as those learning the information in problem solving context or active learning approach were able to transfer their problem-solving skills to real world contexts.

Students are usually asked to do computations using "given, required, and solution" steps which is a 'chug' and 'plug' kind of problem solving. Lecture courses, examples, and examinations all emphasized procedural/numerical calculations using thermodynamics as well as other physics or science equations. There were no opportunities to elicit students' qualitative explanations to find out what they understood before they started the semester/course and little opportunity to develop their qualitative understanding during the course /syllabus coverage. Instead, students learnt to manipulate symbols without

understanding the concepts that they represented. By representing thermodynamic definitions only in terms of mathematical relationships, for example by defining Gibbs free energy solely as the relationship: $G=H-TS$, the students are allowed to ignore the intrinsic meaning of the expression while they concentrate on using it to perform calculations. It is necessary, therefore, to define physical quantities such as entropy and Gibbs free energy qualitatively before the introduction of their mathematical relation. According to “Ethiopian First National Learning Assessment of Grades 10 and 12 Students” Physics performance was the least in both grade levels (MoE, 2011: 12-13). This could be due to lack of conceptual understanding in the science and mathematics subjects. “The perpetuation of recall type of education has the negative effect of intelligence suppression, blocking one’s imagination and reasoning, by weakening the human curiosity to venture into the unknown, and what we call problem solving capability” (Popper, 2002 in Amare, 2009: 429). According to the Third National Learning Assessment, Grade 8 students’ national exam mean score was 35.6% and Grade 10 students’ national exam mean score was 38.09 % (Takele, et al., 2007; in Amare, 2009:416) which confirms a poor achievement status, a figure significantly lower than the requirements of MOE(50%). My own study on Addis Ababa University physics undergraduate students has shown that students lack clear pattern in problem solving skills when taught by traditional lecture method (Shimeles, 2010). This is indicative of one of the many failures of our curricula in the past for which research of this type is absolutely necessary.

In my study, I used the contents of grade 12 *Physical Thermodynamics* unit and *Chemical Thermodynamics* unit of 2010/2011 syllabus for Grade 12 Physics and Chemistry subjects. This means that the model is twice tested in two relatively very close contexts on the same group of students. The aim of testing the model twice is dictated by the goal of empirically justifying and validating with evidence whether the model holds authentic without a reasonable doubt. The research also aims to check, in addition to conceptual change, whether transfer of knowledge between two closely related contexts will take place. As we all know transfer of school science concepts and understanding to real world contexts is one of the most difficult problems of science education. Thermodynamics is selected because it is one of the most complex domains of physics in which students usually feel a lot of learning difficulties. Even though knowledge transfer was first suggested by Behaviorists, it became the subject of greater theoretical and practical importance in cognitivism and constructivism as well. Vosinadou (2007) asserted that any learning theory which can not address the problem of knowledge transfer is an inadequate learning theory. According to Perkins (1992), students learning by the traditional approach failed to transfer their textbook science problem- solving to real world contexts where as those learning the information in problem solving context or active learning approach were able to transfer their problem-solving skills to real world contexts.

Concepts are basic building blocks in the structure of knowledge of the subject. For example, metal, semiconductor, force, acceleration, charge, mass, heat, temperature, entropy, enthalpy, etc. are basic concepts in physics and without clear understanding of these basic building blocks no physics instruction will be effective. The second higher level in the structure of knowledge is the principles of the subject. Principles show relationships between concepts. For example, the phrase “metals are good conductors of heat” is a principle. It shows the relationship between three concepts, namely, metal, conductor, and heat. The third higher level in the structure of knowledge is the laws of the subject. Laws are universal and has wider realm of applicability and also comprise groups of principles. For example, the first law of thermodynamics comprises principles for: adiabatic process, isothermal process, isobaric process, isochoric process, quasi-static process etc. The fourth higher level in the structure of knowledge is the theories of the subject. Theories show relationships between groups of laws. For example, the phenomenological theory of thermodynamics bases itself on the relationships between: the zeroth, the first, the second and third laws of thermodynamics and electromagnetic theory depends on relationships between: Ohm’s law, Gauss’s law, Ampere’s law, Faraday’s law, lenz’s law, etc. All these structures will not be effectively understood unless concepts as basic building blocks are deeply understood. There are two types of procedural understanding—understanding of procedures and understanding of concepts underlying procedures. At present no emphasis is given to understanding of concepts underlying procedures. Procedural knowledge without conceptual knowledge results in superficial, fully complied and automated kind of understanding and we do not know for sure if there is a deep procedural understanding or correct understanding of procedures under such conditions. On the other hand, conceptual knowledge without procedural knowledge may result in superficial understanding but we do not know for sure if there is deep conceptual understanding under such conditions. A separate study needs to be conducted on understanding of procedures. Complete understanding involves both an understanding of concepts and an understanding of procedures.

The main emphasis of our science curriculum thus far seems to be on the quantitative and mathematical aspects of the subject. Students learn by rote the facility to carryout calculations. Incentives and encouragements were given to correct numerical answers, but not to construction of proper qualitative meanings for the ideas/concepts involved in the calculations. All concepts in mathematical relations need to be qualitatively described. Teachers need to provide students with qualitative explanations of thermodynamic relationships, as the students do not read in mathematical relationships all the meaning that an equation carries. Students do this usually without understanding the underlying concepts and even then not good at problems requiring some tricky computations except the trivial ones. Examination

questions should be framed in that they require students to demonstrate both an understanding of concepts and procedures. And if we always ask for numerical calculations, this can only serve to emphasize competence in manipulating equations which gives the impression of all that is needed to learn science subjects. Entwistle and Entwistle (1991) found that, even when the lecturer or teacher had admirable aims for conceptual understanding, unless examination papers reflect this, students were strongly influenced into rote learning. Traditional methods of instruction emphasize rote memorization of procedures without proper understanding for underlying concepts and these are not effective in achieving deep understanding and problem solving skills.

This practice motivated me to take up the current study and develop a science conceptual change model which will eventually help students to be good at both conceptual understanding and computational techniques. Misconceptions, alternative conceptions and preconceptions (intuitive conceptions) are prevalent in the current study of science subjects. Unless we address these misconceptions and hence change them so that they are replaced with the scientific conceptions, we may not achieve the goal of good quality science education in Ethiopia. I added the word '**spiral**' to conceptually bridge the banks of the metaphoric theoretical river and integrated the two categories of learning theories divided based on the source and repository of knowledge. The 'Cognitive' side argues that the individual mind is the source and repository of knowledge and under this category the following learning theories are grouped: 'Personal construct theory' of Kelly (1955), 'Radical constructivism' of von Glasersfeld' (1995), 'Cognitive constructivism' of Piaget' (1985), etc. on one hand and the 'Socio-cultural'/'Situative' side argues that the social environment is the source and repository of knowledge and under this category the following learning theories are grouped: 'Socio-culturalism,'(Greeno and Vande Sande, 2007); 'Social constructivism' of Vygotsky (1978); 'Social learning theory of Bandura' (1977); 'Situative cognition of Lave' (1988), Lave and Wegner (1991), etc. on the other hand. Many researchers believe that the two categories mentioned above are unbridgeable while others believe that bridging is the only way forward, the debate is still ongoing. I took the side of the latter group and wanted to spirally bridge the two sides of theories of knowledge by claiming that the source and repository of knowledge is in both and knowledge is generated in the process of interplay between the person and the socio-cultural environment. Such interplay is modeled by a three dimensional spiral starting at the base of the conical helix and progressing around its axis which I called the axis of learning. The spiral touches in cyclical manner alternatively the cognitive and the socio-cultural sides in an effort to bridge the two categories of learning theories. I am not the first to use the 'spiral' in developing a learning theory model. Basiel (1998) used a spiral function for web-based construction of knowledge. Vygotsky (1978) mentioned the term 'spiral' in relation to language learning (word-thought-word) and cognitive development.

Many researchers, such as Hatano (1994), Murphy (2007), Vosniadou (2007), Thagard (1992), Greeno and van Sande (2007), Halldén and associates (2007) etc., have suggested that the future of good science learning is by using some kind of combination of the 'cognitive' and 'socio-cultural' perspectives. Based on these premises, I proposed SCSMCC as a model of conceptual change in the sciences and empirically tested it. As indicated earlier the spiral model is hailed as a superior method of teaching science. We are teaching our students lower order thinking skills in that we want them to recall and recognize facts and theories. My study on undergraduate physics manuals using content analysis method has shown that the experiments address lower cognitive skills (Shimeles, 2010). Similarly, students lack higher order metacognitive thinking skills and conceptual understanding needed for problem solving when taught by traditional lecture methods (Shimeles, 2010). Conceptual understanding and metacognitive thinking are higher order psychological processes while factual knowledge and procedural understanding are lower order psychological processes. The learning model developed in this thesis shows that knowledge transfer from one situation to another is quite difficult if not impossible if we use socio-cultural or situative learning alone. Students find it difficult to relate and connect what is learned in one context to another context. On the other hand, students find it difficult to apply abstract and general concepts in different contexts/situations if we teach them using individual cognition or independent reasoning alone. Cognition, which is context-insensitive and abstract and socio-culturalism, which is context-sensitive and concrete when taken together can improve transfer of knowledge from one situation to another. The abstraction provides a linkage or connection between different contexts in which knowledge of the domain can be applied. Knowledge in different contexts is fragmented and lack coherence and integration. Abstract knowledge even though difficult in application is coherent and provides the essential tools for connecting and integrating different contexts. Active engagement in critical thinking is the core of any learning by way of sharpening the dialogue or discussion and digging deeper into the dialogue or the discussion. Digging deeper in dialogue or discussions help us make connections between different ideas or multiple perspectives which can be raised regarding different contexts. The study, therefore, tries to test how, the SCSMCC as integrated model of conceptual change, can improve transfer of knowledge, in addition to conceptual change, from one content area to another in secondary school setting and eventually apply the model in studying transfer of knowledge from classroom to real world context.

1.4.1 Research Hypotheses of the Study

The overarching or main null hypothesis of the study is:

H₀: The integrated model of conceptual change, based on critical analytic method, is not more effective in achieving deep understanding than the traditional method of transmission of information.

The following are the null sub-hypotheses of the main/overarching null hypothesis:

- H₀₁:** The experimental group, who were taught by using the integrated model of conceptual change, will not learn thermodynamics more than the comparison group who were taught by the traditional method.
- H₀₂:** Female students in the experimental group will not be empowered by the integrated model of conceptual change more than those in the comparison group who were taught by the traditional method.
- H₀₃:** The performance of low achiever students in the experimental group will not be enhanced by the integrated model of conceptual change more than those in the comparison group who were taught by the traditional method.
- H₀₄:** The integrated model of conceptual change cannot predict deep understanding more than the traditional model of transmission of knowledge.
- H₀₅:** The integrated model of conceptual change has no effect on conceptual and procedural understandings more than the traditional model of transmission of knowledge.
- H₀₆:** The holistic model of conceptual change has no effect on knowledge and extra rational constructs transfers in school setting.

The above research hypotheses are tested to arrive at a conclusion whether the SCSMCC as integrated model of conceptual change is effective in bringing about deeper conceptual understandings, and knowledge transfer that alleviate the problem of low pass marks in national exams and lack of professional competence in the science job markets. In most of the cases the assumption is that activation of an appropriate schema which would facilitate conceptual change and deeper conceptual understanding will occur when students are instructed using SCSMCC-based CAPs instructional strategy and this is related to a greater degree of affective, motivational and socio-cultural changes that are likely to co-occur.

1.4.2 Objectives of the Study

The general objective of this study is:

- To show the superiority of the integrated model of conceptual change (SCSMCC-based RPC method) over the traditional method of transmission of information.

The specific objectives of this study are:

- To show that the treatment group has learned thermodynamics more than the control group.
- To indicate that the SCSMCC as the integrated model of conceptual change has empowered female students.
- To explicate that the SCSMCC as holistic model of conceptual change has the advantage of enhancing the performance of low achievers.

- To indicate that the SCSMCC as integrated model of conceptual change can predict deep understanding.
- To arrive at a conclusion that the SCSMCC as integrated model of conceptual change has a positive effect on conceptual and procedural understandings more than the traditional method of transmission of knowledge.
- To show that the SCSMCC as holistic model of conceptual change has a positive effect on knowledge and extra rational constructs transfers.

1.5 The Theoretical Framework of the Study

Constructivism, and that human beings are knowledge constructors, is the leading metaphor of human learning since 1970's. During those days constructivism was following monist philosophy but later on as different sects appeared it fell back to dualist philosophy. The two major sects or variants of constructivism are: radical constructivism and social constructivism. Aspects of Piagetian(1937, 1985), Ausubelian(1978), Vygotskian(1978) and Brunerian(1957) learning theories were used in constructivist learning theory such as importance of ascertaining prior knowledge or existing cognitive frame works, use of dissonant events or relevant information to effect conceptual change. Naussbaum and Novick (1982:184) wrote "the conclusions of leading theories in cognitive psychology seem, therefore, to be mutually supportive." Yeany (1991:3) after critically analyzing all of the existing learning theories suggested that the theory "seems so elastic that, instead of demanding adherence, it simply accommodates many perspectives." Constructivist epistemology contends that science cannot transcend the domain of experience. Scientific theories are taken as models which help and order that domain of knowledge. Models raise questions such as: in semantics--what is the representational function that models perform?; In ontology--what kinds of things are models?; In epistemology —how do we learn with models? And in philosophy of science--how do models relate to theory? The task of scientists is to create conceptual structures and fit their experience with it. Scientists invent theoretical models and test their viability in repeated and controlled experiences we call experiments.

Constructivism is more of an epistemology (philosophy) not a strategy of teaching. Constructivism not only addresses knowledge construction at content level, but also addresses issues of metacognition such as nature of human interaction and nature of science. According to Driver and associates (1994), Piaget's theory and theories based on his ideas have been characterized as personal constructivist theories as they focus on the individual's personal construction of meaning through interaction with the physical environment.

Based on the ideas of Vygotsky (1978), social constructivism maintains that all higher mental functions originate in social interaction. Meanings can be externally and socially constructed before learners make them personal and internalize them. Cognitive processing on both the external or social and individual or internal planes is always mediated by tools and signs, most importantly language. According to Wretsch & Toma (1995), Vygotsky used the term *inner speech* to label processes that others would have referred to as cognition or information processing. Vygotsky(1978:86) said, *learning takes place first on the social plane* which I contend that such primacy of social or individual is unnecessary and we should consider that both of them started at about the same time and evolved together in a continuous manner. Unless the individual is ready to learn, no learning can actually take place. When Vygotsky claimed that learning must be scaffolded, he means that the learner first tried to learn by his own but unable to make progress without the social or group support. Vygotsky (1978:86) also postulated that children are able to engage in problem-solving tasks “under adult guidance or in collaboration with more capable peers” which they cannot do it independently. Adults consciously control these tasks in the process of scaffolding the child and dialogue with more knowledgeable and skilled members of the community allows the child to learn social languages. According to Bakhtin (1986), these social languages expanded Vygotsky’s ideas to provide more emphasis to the socio-cultural setting on which learning takes place.

The social constructivist instructional strategies which involve conceptual changes include--the individual experience of learners in the classroom instruction, the nature of language used in the group, the nature of group interactions, and the historical, cultural, and institutional settings of the group interactions. That is why I contend that the individual-cognitive and socio-cultural contextual factors should be alternately planned to achieve conceptual understanding. Social constructivism advanced learner’s active participation and gave heightened recognition to the social nature of learning.

Theories about conceptual change have been built on the premises of Kuhn’s (1962) idea of theory change and Piaget’s (1929) idea of assimilation, accommodation and equilibration. According to Dykstra et al.(1992), conceptual change can involve “*differentiation* in which new concepts emerge from more general concepts, *class extension* in which existing concepts become cases of another subsuming concept and *re-conceptualization* in which nature of relationship between concepts changes significantly”. According to Posner and associates (1982) classic study on conceptual change, after dissatisfaction with existing conceptions, requirements for conceptual change are that the new conception be intelligible, plausible, and fruitful. The status of a conception is increased as more of these three conditions are met (Hewson, 1996). The instructional strategy used by these authors is creation of cognitive conflict between existing conceptions held by the child and conceptions held by the scientific community.

As it tried to overcome the debate between empiricism and rationalism using the dualist separation of the human mind and the external world, the constructivist metaphor of cognitive psychology emerged in the 1970's (Gregen, 1985). I, therefore, advanced a model of learning for conceptual change that cyclically and spirally use both individual and social construction of knowledge. Learning and teaching start at about the same time in a classroom context and this shows why the individual and social formation of concepts axes unite at the base of the cone of learning in SCSMCC. According to cognitive or radical constructivists (ex. von Glasersfeld, 1995) knowledge is not a self-sufficient entity and that knowledge is not directly transmittable from person to person, but rather is individually and idiosyncratically constructed or discovered. A world has mind-dependent existence and all persons cannot have similar and uniform cognition. Social constructivists considered learning as situation-specific and context-bound activity (Eiggen & Kauchak, 1999; McInerney & McInerney, 2002; Woolfolk, 2001). Terhart (2003) contends that constructivism did not present a new didactic paradigm different from traditional theories. Constructivism does not introduce a paradigm shift from the traditional dualist framework of thinking. According to Hualiu & Matthews (2005), a paradigm shift requires a deeper level of correction. These authors summarized that the behaviorist and constructivist emphases on the objective and the subjective, the universe and the mind, they found not two but one singular theoretical paradigm, which is that of dualism. However, my SCSMCC does not accept such dualist approach of regressing towards the past rather than progressing towards the future. The model I developed requires one functionally unified and monist theoretical paradigm which conceptualizes the relationships of the mind with the external world as a unified whole.

Piaget and Vygotsky are polarized along the individual and social because of the dualist sects which exist implicitly in constructivist literature. Behaviorists failed to address the mind-body relationship, but constructivism tried to overcome the difficulty in thinking by postulating the interactivity of human mind and the world. The constructivists are epistemologically social relativist, and such relativism does not entail a paradigm or gestalt shift (Hualiu and Matthews, 2005). According to Liu (1989), "subjectivity should not be superior to objectivity, for concrete laws of problem solving must be established on the basis of empirical evidence". Vygotsky(1978) does not conceive the mind as something independent of the social and cultural group.

Vygotsky(1978) stresses the use of semantics, pragmatics and study of discourse and one cannot reduce beyond word meaning without great loss in understanding. Robbins (2001) describes the socio-psychological nature of word meaning and its function in intellectual development as:

The word does not relate to a single object, but to an entire group or class of objects. Therefore, every word is a concealed generalization. From a psychological perspective, word meaning is first and foremost a generalization. It is not difficult to see that generalization is a verbal act of thought; its reflection of reality differs radically from that of immediate sensation or perception. It has been said that the dialectical leap is not only a transition from matter that is incapable of sensation to matter that is capable of sensation, but a transition from sensation to thought. This implies that reality is reflected in consciousness in a qualitatively different way in thinking than it is in immediate sensation. This qualitative difference is primarily a function of a generalized reflection of reality. ...At the same time, however, meaning is an inseparable part of the word; it belongs not only to the domain of thought but to the domain of speech. It is obvious then, that our method must be that of semantic analysis. (Robbins, 2001:47)

Each word has dual meanings: the objective reality or phenomenon it refers to and the relationships it has with other words. These levels together give the word its social semiotic significance. The transition from immediate sensation to thinking or cognition is what creates a difference between humans and animals.

The relationship between the mind and reality are bound in, philosophy of science, by two extreme views: one of them is complete correspondence of mind and reality which is the view held by natural scientists. The other view is a complete incommensurability of mind and reality which is the view held by professionals in humanities and social science. The former is positivist/fundamentalist or objectivist and the latter is epistemologically relativist/existentialist or a philosophical perspective which considers life as meaningless. The underlying implications of positivist philosophy are: (a) understandability of nature to the human mind;(b) the pursuit of truth is going to be endless effort, for the representation of the universe by the human mind can only be true to the human mind and cannot be objectively asserted as true to the universe as such; and (c) the pursuit of truth is not meaningless for we do not require absolute whole truth but human rationality is bringing us to an ever closer representation of what truth is (Liu,1998). According to ancient Greek philosophers, rationalism and empiricism were the two sources of knowledge. Rationalism is a philosophical paradigm advanced by Plato in which he stresses the power of *a priori* reasoning in obtaining substantive truths about the world in which we exist (Aune, 1970). Essentially the rationalist claim is that one can know truth or falsify a statement without the need for observation or experiment or by employment of innate ideas alone. Contrary to Plato's notions of innate ideas and the superiority of reason, Aristotle's, Plato's disciple, work emphasized the power of sensory experience such as observation and experiment in the generation of knowledge.

Empiricism refers to a philosophical position in which *a posteriori* reasoning, that is, reasoning from sense experience or observation provides a mechanism for obtaining substantive knowledge and truths about the world. These two categories are, however, not mutually exclusive but rather complementary and overlapping. Empirical here means verifiable by observation, evidence, or data yielding a proof or strong confirmation. The theoretical framework of constructivism posits that a person constructs his/her own reality. According to constructivism, a person perceives phenomenon by interpreting what is happening and acts depending on that interpretation. A person cannot observe phenomena in a strictly objective sense but in the way those things really happen. In contrast, persons acquire unique *personal constructs* or personalized views, which they use to interpret whatever that comes to their attention. Therefore, as opposed to the positivist's "single reality- out- there" and hence traditional curriculum, constructivism assumes that every individual has his/her own version of reality and hence multiple realities exist. Only through consensus and shared understanding we arrive at a common reality. Constructivist learning theory holds that learning is always based/builds upon knowledge that a learner already knows or schema. Constructivism asserts that learning is more effective when a student is actively engaged in the learning process rather than passively receiving knowledge and therefore all learning should be filtered through pre-existing schemata. Most constructivist methods use variants of guided discovery where direct instruction is not used and lead the student through series of questions and activities in order to discover, discuss, appreciate and externalize or express the new knowledge through verbal speech.

Constructivist learning theory asserts that meaningful knowledge can be constructed based on prior knowledge. Constructivists consider learners not as blank slates onto which information is itched but as builders of knowledge which make sense of it according to his/her current conceptions. According to this learning theory, children learn better when they are allowed to construct a personal understanding based on experience and reflection on that experience. Some constructivist activities are: experimentation, do experiment personally and discuss the result in groups; research projects, research a topic individually and present findings to the group or whole class; field trips, allows them to put the concepts and ideas discussed in class in a real-world context. Field trips should be followed by class discussions. Films, provide visual context into the learning experience; class discussion is a robust method and can be used with all of the methods discussed above and it is one of the defining properties of constructivist teaching methods.

Constructivists believe that objective knowledge cannot exist but rather all of us are involved in constructing our own words, part of which we take as being shared by others. Constructivists believe in truth but not in a truth that have been constructed by somebody and thus the new idea is not imposed on

the learner. According to constructivism, all knowledge is linked to a subject who knows and it is profoundly subjective and therefore knowledge of reality is constructed in the mind of learners- -it is not objective and singular, "out-there", as positivists would like to think. Knowledge construction is a process--not instantaneous--and involves reorganization of initial knowledge structure which also involves reconstruction to change conceptions. Conceptions play an organizational role in thinking and learning but also affect our attitudes, views, values, feelings and beliefs. In constructivism, Popperian *inter subjective construction of reality* concept is central as a philosophical foundation. Anti-positivist's criticize science as mechanistic and reductionist and which exclude choice, freedom, individuality, and moral responsibility.

Positivist social science fails to take into account our unique ability to interpret our experiences and through reflection represent them to ourselves. It has been rejected that human behavior is governed, like physical objects, by general, universal laws and characterized by underlying regularities. This is a stance of rejecting detached and objective observer. "Many events are not reducible to simplistic interpretations and hence 'thick descriptions' are essential rather than reductionism" (Geertz, 1973b). According to this last author events and individuals are unique and largely non-generalizable. Reality is multi-layered and complex and multiple perspectives on a single event and situations are possible. But anti-positivists have gone too far in abandoning scientific procedures of verification and thereby given up hope of discovering useful generalizations about behavior (Mead, 1934). Just as positivist theories can be criticized for their macro-sociological persuasion, so is interpretive and qualitative research criticized for its narrowing micro-sociological persuasion. Positivists base their assumptions on objectivity, measurability, predictability, controllability, and patterning, the construction of laws and rules of behavior and the ascription of causality. In this context, it is worthwhile to mention the contribution of the medieval Ethiopian philosopher Zerea Yacob who lived during the reign of King Zerea Yacob who shares the same name as the philosopher. The philosopher foresaw the work of the French positivist philosopher of Algerian origin Augustine Comte and he thought and believed that religion is not the only way of generating knowledge and other secular ways exist which use questioning and detailed investigation to understand nature and society. The medieval time was known for the dominance of religion in every aspect of life and philosophers such as Zerea Yacob were prosecuted not only in Africa or Ethiopia but also in Europe. Galileo Galili, the scientist and father of the experimental method, was severely prosecuted by the Roman Catholic Church. However, Ethiopians never benefited from the works of great Ethiopian thinkers such as Zerea Yacob, as the dominance of religion extended from the medieval era to the modern age. This created a kind of people who are prepared to believe but who are not ready to question and change their conceptions of life.

According to SCSMCC model, we Ethiopians were trapped by our tradition and our knowledge was simply the result of socio-cultural sharing of information with little or no individual contribution by people such as Zerea Yacob and his disciple Wolde Hiwot as their ideas was overwhelmingly suppressed by religion and culture. And hence our knowledge lacked depth and breadth and as a result we were unable to solve problems, become creative and innovative. Zerea Yacob tried to show that an alternative epistemology to religious philosophy exists and he contributed to what was later on known as positivist epistemology. The age old knowledge of Ethiopians was transferred from generation to generation without criticality and critical reflection or critical self reflection to guide critical action or reflective practice. As critical theory suggests that was why Ethiopians were not emancipated from the culture of religious dominance and passive acceptance of ideas for granted. We are, in some sense, still living in the culture of the middle ages and lack cultural development which fits 21st century realities.

Interpretive paradigms strive for understanding and interpreting the world in terms of its actors. In the former, the observed phenomena are important. In the latter, meanings and interpretations are paramount. This is a research which is open-ended, explanatory, contributes something original to the substantive field and extends the frontiers of knowledge. The new holistic SCSMCC is using a synergy of individual and social construction of knowledge. The methodology used is a mixed methodology called the third paradigm and it is used to lessen the tension that is generated between normative and interpretive approaches. Merton and Kandal (1946) expressed it as: “social scientists have come to abandon the spurious choice between qualitative and quantitative data: they are concerned rather with that combination of both which makes use of the most valuable features of each. The problem becomes one of determining at which points they should adopt one, and at which the other, approach.”

1.5.1 Conceptual Frame Work of the Study

A conceptual framework shows the mesh of main concepts and the key factors or variables, constructs, and the presumed relationships among them. A conceptual framework can be simple or complex, theory-based or result of imagination and experience. Figure 1.1 and Figure 1.2 show the conceptual framework of this study. The two figures show the conceptual change model and the knowledge transfer between two closely similar contexts, respectively.

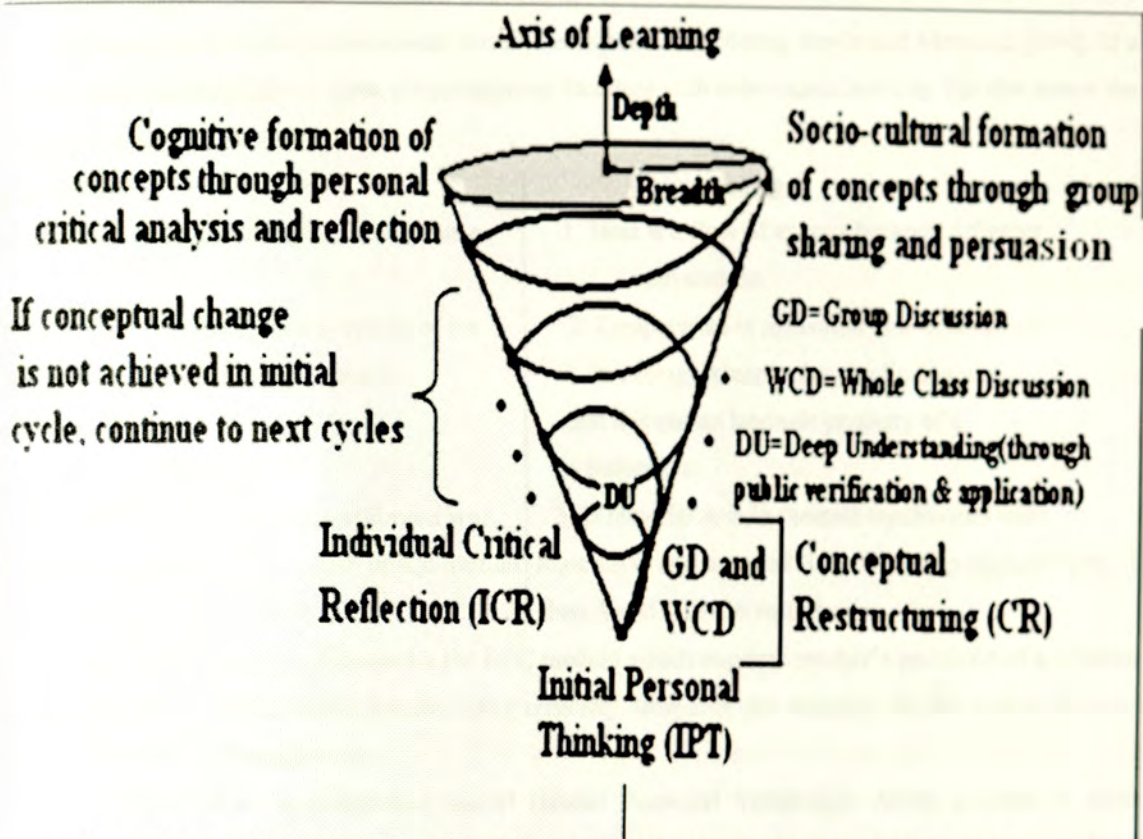
1.5.2 The Proposed “Spiral Cognitive-Sociocultural Model of Conceptual Change (SCSMCC)”

There are a number of conceptual change models in science education. As discussed earlier, Posner and associates (1982), classical/orthodox model of conceptual change (OMCC) used cognitive conflict as a strategy for conceptual change in which four steps are used: (a) dissatisfaction with existing conceptions, (b) there must be a new conception that is intelligible, (c) the new conception must appear to be plausible,

and (d) the new conception should suggest the possibility of a fruitful program. This model considered a child like scientist. Conceptual change was compared with Kuhn's (1962) theory of change and conceptual growth as developmental process of Piaget (1929). The conceptual change strategy used was based on cognitive conflict and it was the source of much conceptual change research in the 1980s and early 1990s. This model was named as a "cold" model of conceptual change by Pintrich and associates (1993), since it did not take into account motivational, affective, and socio-cultural contextual factors except the cognitive/rational factors.

Dole and Sinatra (1998), based on suggestions put forward by Pintrich and associates (1993), came up with a model which takes into account motivational factors. This model, called "Cognitive Reconstruction of Knowledge Model (CRKM)", was taken as "warm" model of conceptual change. Dole & Sinatra (1998) raised the "temperature" of their model by including motivational factors in addition to cognitive factors. Gregoire(2003) came up with another model of conceptual change which she named as "Cognitive-Affective Model of Conceptual Change(CAMCC)". She added to cognitive factors, motivational and affective factors and therefore claimed to have fulfilled the vision set out in Pintrich and associates' (1993) article. Because of the inclusion of affective factors, over CRKM, she claimed to have developed a "hot" model of conceptual change, raising the temperature of her conceptual change model one step further compared to Dole & Sinatra's (1998) "warm" model. Murphy (2007) came up with a model of knowledge and belief change for conceptual change. Her model not only takes affective and motivational factors(beliefs) as facilitators of conceptual change, but requires that these factors themselves change in addition to conceptual change. Her model was a modification and further elaboration of Carey's (1985) cognitive developmental model of conceptual change which has three steps: accretion, weak restructuring, and radical/strong restructuring. Carey's (1985) model of conceptual change is simply an elaboration of Piaget's (1929): assimilation, accommodation, and equilibration and is a "cold" model of conceptual change since it addresses cognitive factors only.

In my proposed holistic SCSMCC, the changes in motivation, attitude, perceptions about socio-cultural factors in CAPs strategies and learner study skills as well as conceptual change and knowledge transfer are considered. The SCSMCC is developed to serve as a conceptual and theoretical frame work of this study. The SCSMCC is developed by using ideas taken from literature review. This research tried to test the model empirically on two different occasions, to see if it consistently up holds that the model is really a valid one. Such repeated testing allowed me to check for knowledge transfer in addition to conceptual change. The SCSMCC is shown in Figure 1.1.



Engage Door Keepers Such As Motivation, Affection & Socio-cultural Factors

Figure 1. 1: The Holistic Spiral Cognitive-Sociocultural Model of Conceptual Change (SCSMCC)

As shown in figure 1.1, each cycle of the spiral depicts six steps:

Phase 1 of SCSMCC model (Engaging the Door Keepers-Motivation, Affection, and Socio-Cultural Contextual Factors): Teacher introduces the topic of the lesson while at the same time motivating and arousing their curiosity and interest in the topic. The RPC strategy used was based on my SCSMCC model of conceptual change. In this strategy the teacher starts the lesson by motivating and nurturing interest in the particular topic. For example, by telling a history of the particular scientist who contributed to the topic under study, some self-efficacy stories from the teacher or a capable peer etc. This should be done in a short and precise manner for the purpose of not wasting class time. The students should use initial active listening to grasp the task of the day and the teacher should ascertain that s/he has full control over the class. The teacher writes the two categories of valid and invalid conceptions side by side on the board and asks students to decide through argument, evidence and justification as to which category they think is the scientifically correct and valid conception (5 minutes). The word "misconception" or invalid conception "refers to: (1) students' mistaken answers to a particular situation,

(2) students' ideas which cause mistaken answers about a particular situation, and (3) students' beliefs about how the world works different than that of the scientists" (Dykstra, Boyle and Monarch, 1992). If a student holds misconceptions, these misconceptions interfere with subsequent learning. For this lesson the categories presented were:

<u>Category one</u>	<u>Category two</u>
1. Heat has a property of matter or substance	1. Heat is a flow of energy between different substances
2. Like heat, temperature is a property of the Material from which a body is made	2. Temperature is measured as a measure of an average kinetic energy of molecules and it is not an intrinsic property of a Substance
3. If material A is in thermal equilibrium with Material C and material B is also in equilibrium then A and B are not in equilibrium	3. If material A is in thermal equilibrium with Material C and material B is also in equilibrium With C, then A and B are in equilibrium

The creation of categories is dictated by the RPC method which requires teacher's provision of a learning material on which learners take position after critically analyzing the material. In this lesson plan the incorrect category is category one.

Phase 2 of SCSMCC as integrated model (Initial Personal Thinking): Allow students to think individually for 3 minutes. They reorganize their thinking about their background knowledge associated with the topic and identify points of difficulty. Background/prior knowledge when organized and patterned, it will help in knowledge restructuring during, say, classroom discussion. That is what I demanded in this phase of my SCSMCC model. And take position individually as to which category they think is correct. The Initial Personal Thinking (IPT) phase is actually an exploratory personal discovery phase. Involving students in discussions without some personal thinking results in wastage of time. Students have to learn to think before they actually speak their minds. This should be a good practice well into the rest of their life. Formal reasoning and pre-existing knowledge play an important role in the development of students' conceptions.

Phase 3 of SCSMCC as integrated model (Small Group Discussion): Teacher prompts the students to share ideas and discuss with pre-planned nearest neighbor discussion groups in the process of restructuring their conceptions and come to a group consensus and select a spokesperson for their position's presentation (5 minutes).

Phase 4 of SCSMCC as integrated model (Whole Class Discussion): Each group participates via their spokesperson in whole class discussion and report their position, doubts, and conceptions supported by evidence, reasoning and justification in the process of restructuring their conceptions. The teacher as a

change agent, facilitates the process of whole class discussion, clarifies on doubts and drives the learners towards whole class consensus (7 minutes) as to which category is correct and why it is so. The teacher needs to sharpen and focus the discussion by identifying direction, sorting ideas for relevance, and focusing on key points. In the discussions, conceptual restructuring is expected to happen.

Phase 5 of SCSMCC as integrated model (Individual Critical Reflection): Students individually look back and critically reflect on and evaluate all what has been discussed, thought, what went wrong, and how it was corrected and any lessons to be drawn from this learning experience. Students need to dig deeper by utilizing full-spectrum questioning, making connections, and honoring multiple perspectives raised during discussions. The teacher provides, in the mean time, notes on correct scientific conceptions and explains why they differ from our intuitive every day conceptions of Thermodynamic phenomena and gives challenging conceptual questions and problems involving both conceptual and procedural understandings (10 minutes). Students are required to question existing beliefs and assumptions. This individual reflection phase puts conceptual restructuring on a sound basis.

Phase 6 of SCSMCC as integrated model (Deep Understanding): demonstration of deep understanding by answering challenging conceptual questions and solving problems which resemble real life situations. Application of his/her knowledge in answering conceptual questions and solving problems demonstrates his/her deep understanding of the topic or learning task (10 minutes). This phase reveals whether conceptual change has really occurred. If the change did not occur in the classroom or initial cycle, then the next cycles should be tried by way of tutorials or home work/ assignment/ project or a group study under the guidance of capable peer or adult-expert, and so on. The spiral in the model bridges individual and social formation of concepts in a continuous manner and shows that learning is a life-long process.

The six phases of the SCSMCC as integrated model comprise one cycle of the spiral. If the learner did not achieve deep understanding in the initial cycle s/he can continue outside the classroom by initiating similar cycles. If strong conceptual change cannot be achieved in the initial cycle, the six steps can be repeated on higher second cycle, and so on outside the classroom, at home, at work place etc., to the rest of his/her life, when the individual chooses a career in the concepts being taught in the classroom. If conceptual change is not achieved at one grade level, it may be achieved at a higher grade level, and so on. Conceptual change can be a long time (evolutionary) or short time (revolutionary) process depending on the individual learner's particular academic nature. In this sense, then, learning becomes a dependent variable on motivation, attitude, socio-cultural factors in CAPs strategies and study skills in addition to cognitive factors in understanding thermodynamic concepts. The function below shows dependence of learning on the above mentioned variables.

$$L = f(K, T, CAPs, M, S, A) \dots\dots\dots(1)$$

Where L= Learning through SCSMCC based on CAPs = Critical Analytic Pedagogies (ex., RPC);

f= function;

K= Prior knowledge/experience (reorganized in the initial personal thinking phase);

T= Learning task/message (presented in the engage motivation, affection and socio-cultural phase);

CAPs= Critical Analytic Pedagogies;

M = Student Motivation;

S= Student Study Skills; and

A = Learner Attitude.

The SCSMCC describe a process of conceptual change that involves cognitive, motivational, affective, and socio-cultural factors leading to a choice between existing knowledge and the instructional message. Knowledge construction and reconstruction is effected through the spiral interplay of personal/cognitive construction and socio-cultural construction that evolves in time with increasing breadth and depth. The socio-cultural refines personal construction of knowledge. The following figure shows a conceptual framework for this study regarding conceptual change and knowledge transfer.

Horizontal Transfer of Concepts--Model Deployment

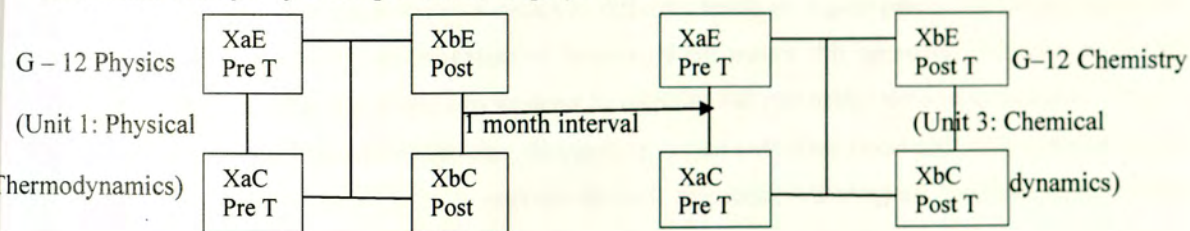


Figure 1. 2: Model of horizontally equivalent (matched) Chemistry and Physics groups used in the study of conceptual change and transfer of knowledge.

In implementing the integrated SCSMCC, critical analytic pedagogies were used such as persuasive pedagogy and collaborative reasoning. Persuasive pedagogy (PP) requires that teachers and students critically and analytically evaluate prior knowledge and beliefs through the use of reason, evidence, and justification. Essentially within this approach, teachers select materials that require students to take position, and the justification of that position is of central concern during instruction. The teacher's role is that of a change agent.

Teachers help students make their beliefs and knowledge explicit, and thus, challenge students' perceptions and misconceptions (Murphy, 2001). This line of research has empirically shown the strength of argument and discourse in the process of change. Collaborative Reasoning (CR) employs discussion to foster student's critical reading and thinking about text as part of instruction. CR is premised on the idea of reasoned argumentation as a model of critical thinking and aims to encourage students to use reasoned discourse as a means for choosing among alternative perspectives on an issue or a concept. CR discussions foster conversations between students that draw on personal experiences, background knowledge, and text for interpretive support. In the format of collaborative reasoning, the teacher poses a central question deliberately chosen to evoke varying points of view. Students adopt a position on the issue and are encouraged to generate reasons that support their position. Using the text, as well as personal experiences and background knowledge, students proceed to evaluate the reasons and evidence, to consider alternative points of view, and to challenge the argument of others. This discourse intensive approach has been used with and without text as the focus.

Both methods engaged students in reasoned argumentation and challenged opinion and thoughts of others, respond to challenges, and provided evidence or information from the text in defense of their arguments more frequently than did those involved in traditional recitation techniques (Chinn et al., 2001; Chinn and Samarapungavan, 2001). These methods are combined in order to involve learners in group discussion while making their individual reasoning explicit in the group discussions. This RPC method is spiral in that it goes through a series of cycles at differing levels of higher psychological processes that encourage a critical-analytic interrogation of content. What makes this approach effective in altering learner understandings is that it requires students to consider and reconsider their own positions, refine it through group discussions and whole class discussions, take a collective stand and reach consensus with their teacher, while supporting their perspectives with evidence. We integrate students socio-cultural understanding with more cognitively oriented abstract science concepts.

The SCSMCC as holistic model of conceptual change integrates the socio-cultural and cognitive components of change. Students try to understand personally and share with their colleagues in mixed ability pre-planned groups, and further share it with the whole class and the teacher rectifies some of the misconceptions and students reconsider their original position and the process goes on spirally until final perfection and internalization of concepts is achieved. In RPC students are presented with two unlabelled categories of conceptions and misconceptions on the topic of study which are well researched scientific conceptions and student misconceptions. And not to be prescriptive students are allowed to add their own conceptions under each of the categories they think it belongs. Students are then asked to take position

individually by giving reasons for their choice. The process goes on as described above and the teacher finally takes over to conclude the lesson, by showing the right category that is scientifically acceptable. Thus knowledge becomes personally meaningful and socially worthwhile (Shirouzu, 2002). The study tries to compare the SCSM model based RPC strategy with traditional strategy and tries to see which one is more effective in bringing about conceptual change in students. The findings of the research thus obtained can be used to suggest ways of designing and developing a science curriculum that can be used by future science education practitioners and educators to bring about the goal of good quality science education in Ethiopia.

1.6 Significance of the Study

In the preceding years contrary to intentions of ETP (1994), the science curriculum of Ethiopia did not emphasize knowledge construction by the learners as most of the teaching –learning in both the plasma TV and non-plasma TV cases were practicing most of the time lecture-demonstration(MOE Curriculum Guide, 2005; Plasma Manual and guide, 2005) which is a teacher-centered method. In the school where I did my research, however, plasma TV classes were not conducted in the academic year 2010/2011 and a new so-called constructivist curriculum and which was not properly implemented is introduced as I started my treatment of conceptual change and knowledge transfer. The teachers were not given on the job training to implement the new curriculum. The use of conceptual change models is so far unknown in Ethiopian science education. Learning does not occur by transmitting information from the teacher or the text book to the learner's brain. Students are viewed as "blank slates" on to which information is etched by the teacher. I believe that the current science curriculum is not suitable for science learning as it is not purely implementing constructivist learning strategies as shown in the documentary analysis, in chapter three, of this thesis. Students taught using this kind of mixed methods may not achieve deeper conceptual understanding and, therefore, lack sufficient problem solving skills to alleviate/solve the many problems of our nation.

Teachers must be trained well enough in pedagogical techniques as well as in content knowledge in order to implement the curriculum effectively. Therefore, based on this dominantly quasi- experimental (quantitative) and supportive qualitative study which run concurrently, the researcher plans to test SCSMCC that emphasizes deeper conceptual understandings which facilitate a good level of procedural understandings and vice versa. In secondary school curriculum guides, curricular activities rely heavily on textbooks, data and manipulative materials. Where as in constructivist approaches, curricular activities rely heavily on primary sources and regarding the current curriculum it is heavily based on text books and I was unable to see the requirement of provision of primary sources in the curriculum guides and teacher guides which is not very much different from the traditional curriculum. Traditional classroom students

usually work independently on individual basis, where as constructivist classroom students primarily work in groups. In my SCSMCC as integrated model of conceptual change, however, students are required to work both individually and in groups in almost equal proportions. In traditional classrooms curriculum is presented part to whole, with emphasis on basic skills (bottom to top) in which both major and minor concepts are equally taught. In this content loaded curriculum student have little or no time for analyzing and understanding the concepts taught. "In constructivist classrooms curriculum is presented whole to part with emphasis on big/major concepts (top to bottom), where minor concepts are left to student exercises, drills, and practices" (MacNeil, 1996:194). Therefore, the constructivist plan needs a change of content load by emphasizing the teaching of major concepts and leave minor concepts to students home assignments, projects, exercises and classroom drills and practice. Thus we can cover the selected units according to the normal class schedule for both experimental and control groups. In my SCSMCC as holistic model, however, both individual and group works are equally encouraged and valued. The spiral acts like a bridge between the personal cognition and socio-cultural/group learning. Learning is, therefore, the interplay between the individual construction and social construction of knowledge.

Learning in science occurs best when approached from a constructivist point of view (Martin, 2003). Well-designed curriculum documents which combine personal cognition and socio-culturalism can facilitate deeper conceptual understandings and conceptual change. Science subjects are concept-based and should be taught using the SCSMCC as integrated model of conceptual change. Coherence in constructivist conceptual change curriculum fosters increasing sophistication and vividly shows the relationships and connections in critical content knowledge, conceptual understanding and complex performance abilities. The difference between traditional curriculum and the SCSMCC design is that the former is topic-centered and the latter is concept or idea-centered. "Topic-centered curriculum focuses heavily on memorization of facts and **assumes the development of deeper ideas**. Idea (concept)-centered curriculum **focuses on deeper, conceptual ideas and use facts to support the understandings**. **Facts are means not ends for this type of curriculum**" (emphasis added) (Amare, 2009:429).

Conceptual understandings become more sophisticated from primary through secondary to tertiary levels. This is depicted in Figure 1.1 of SCSMCC as integrated model of conceptual change and that the axis of learning points upward through the center of the conical helix showing that learning evolves in the course of time. Conceptual changes take longer periods to be firmly rooted in learners' minds. According to Driver (1985: 198), "When conceptual change does occur, it appears that it is a long-term and slow process". Therefore, curriculum planning should not only take into account conceptual analysis of the

subject or structure of the subject but also learners' prior self-constructed knowledge as shown in the IPT (Initial Personal Thinking) of the SCSMCC model. My pre- treatment study on secondary science curriculum, as shown in Chapter three of this thesis, has shown that there was virtually no model of conceptual change implemented so far which employs CAPs strategies in Ethiopia. And, therefore, it is necessary to test a conceptual change model which enhances deep understanding and knowledge transfer in real world contexts.

1.7 Limitations of the Study

Financial constraint is one limitation of the study and because of the large amount of data collected from the same sections of students, some of the students become disinterested in properly filling the questionnaires towards the end of the treatment period. This happened during the treatment of 'Chemical Thermodynamics' unit. This may have an impact on the results of the study, particularly in studying knowledge transfer from 'Physical Thermodynamics' to 'Chemical Thermodynamics'. The teachers of Chemistry and Physics used for the treatments were different and this may have an impact on knowledge transfer results. The other limitation of the study was multiple treatment interference because the students are exposed to two treatments. And also effect of pretests may have on the posttests. Otherwise the study has gone very well as the school community were very cooperative.

1.8 Delimitation/Scope of the Study

The study is delimited to unit one of Grade 12 Physics 'Physical Thermodynamics' and unit three of Grade 12 'Chemical Thermodynamics' offered to the same groups of students at same school setting, Bole secondary and preparatory school sections 05 and 06 of the academic year 2010/2011.

1.9 Organization of the study

Organization of this PhD thesis uses a book style format which is somewhat different from the alternative format of organization. The chapters of this study are divided into conceptual themes as headings of chapters rather than the traditional break down of: introduction, review of literature, methodology of the study, results and discussion, and conclusion. Even though there are similarities in 'introduction' and 'conclusion' chapters, there are differences in format and sequence of other chapters. For example, 'methods of the research' chapter is presented just after the 'introduction' chapter while in the alternative format it comes after the 'review of literature' chapter.

This study comprises nine chapters:

Chapter one of this study introduces the background, the purpose, the problem statement, theoretical/conceptual framework, as well as significance of the study.

Chapter two presents research methods and procedures used for data collection and analysis.

Chapters three to five divided the traditional 'review of literature' into conceptual themes and relevant research associated with the problem addressed in this study. Chapter three addresses the relevance of learning theories for conceptual change and shows lack of constructivist conceptual change learning models in our current secondary physical science curriculum using documentary analysis of curricular materials. Chapter four presents studies so far done on models of conceptual change and chapter five addresses results of studies so far done on conceptual restructuring in thermodynamics.

Chapters six to eight divided the traditional 'results and discussion' chapter into results of treatment of Grade twelve physical thermodynamics unit, chemical thermodynamics unit and the study of conceptual and procedural understandings, in addition to, knowledge transfer.

Chapter nine offers summary of major findings of the research, conclusions, implications for curriculum design and development and recommendations for further research.

1.10 Conclusions

The model developed through extensive literature survey unites the individual and social contributions to knowledge generation using the spiral as a bridge between them. There was ongoing debate whether knowledge is generated by individual cognition or by social interaction. This research tried to resolve this debate by requiring functionally unified and monist form of individual knowledge generation and knowledge acquired through social interaction. The two forms of knowledge generation need to be balanced and one should be used as a check for the other. The check and balance concept led me to the rejection of Vygotsky's asymmetry in nurturing and inculcating socio-cultural values in the child which in very simple terms lead to teacher-centeredness. The check and balance concept used in my integrated SCSMCC is concomitant with symmetric and learner-centered approaches in which the learner can be equally and actively guided by teacher or capable peers and involve actively in independent learning. Asymmetry requires more social interaction than individual effort as social constructivists would like to see learning. On the other hand, radical or personal constructivists, show asymmetry by requiring more personal learning than social experience sharing in which individual cognition is primary and social interaction is secondary in the process of knowledge generation. Therefore, I used the monist philosophy of Vygotsky which requires functional unity and interdependence of the two kinds of knowledge generation but not his asymmetry and the primacy of the social and the secondary and derivative nature of individual cognition or vice versa of personal constructivists. The cone of learning I developed in Figure 1.1 shows that there is no primacy of one over the other and the two kinds of knowledge generation are symmetric about the axis of learning, one is incomplete and ineffective without the other. In this way, both personal and social constructions of knowledge are equally valued and can feed one another.

CHAPTER TWO: METHODS OF THE RESEARCH

2.1 Introduction

In this chapter, I will try to show my overall design for the research is a mixed methods design in which the quasi-experimental quantitative design is the dominant one while the qualitative design plays a supportive role. The mixed methods design which is currently known as the 'third research paradigm' (Onwuegbuzie and Teddlie's (2003)) emphasizes the combined use of both quantitative and qualitative methodologies. The design shows how I structured the study and the rationale for using mixed methods design. Also, the variables used in the study are described in this chapter. This will be followed by formation of groups and in-depth presentation of the treatment of experimental group in quasi-experimental non-equivalent groups design. In the treatment: the contents used, the six phases of SCSMCC as integrated model and associated RPC method applied, the lesson plan format and activities as well as teachers experience and qualifications are all discussed. Similarly, for the comparison group the contents, the TLD (Traditional Lecture Demonstration) method, lesson plan format and activities are discussed. I have compared the exposures of the two groups in order to show their different treatments. And finally strategy for analysis, assumptions, and limitations are discussed.

2.2 Design of the Research

This study follows what is currently known as the 'third research paradigm' (Onwuegbuzie and Teddlie's (2003)) which draws on strengths and minimize weaknesses of both in single research study. The quantitative design takes care of the breadth of research while the qualitative treats it in depth. Thus, the two data sets when integrated can support each other. The quantitative design is experimental in which experimental and comparison groups are used. The experimental group is the treatment group while the comparison group is the group which did not receive the treatment. As the treatment is not conducted in a controlled environment similar to the Physics/Chemistry laboratory, true experimental design was not used. The experiment was conducted in a field which is in this case a school classroom where total control of the environment is impossible. In such cases the quasi-experimental design is most appropriate and I used one of these designs, namely, the Non-Equivalent Groups Design.

2.2.1 The Non-Equivalent Groups Quasi-experimental Design

As mentioned elsewhere in the study, the quantitative part is the major source of data. This research culture advances the "...the virtues of 'hard', generalizable ...data" (Sieber, 1973:1335). In this research, out of the quasi-experimental designs available, I selected and used the non-equivalent groups design. My design is predominantly a non-equivalent group's quasi-experimental design in which two intact groups/classrooms were purposely selected from Bole secondary and preparatory school Grade 12 students. The selected sections were 05 and 06 of 2010/2011 academic year. These two sections were

found to be almost similar in their Grade 11 final exam results (ability) distributions when checked for all sections the teacher who agreed to participate handles. This is done to minimize the non-equivalence of comparison and experimental groups in our purposive selection right from the outset. The acronyms in Table 2.1 are shown in front matter under ‘Acronyms and Symbols’. Some of them are re-written just after the table for the sake of clarity.

Table 2. 1:The quasi-experimental design of the study

Groups	Pre-Administration	Treatment	Post-Administration
Experimental Group (Section 06)	PTAT and CTAT SAI-II SMQ LSQ SSI	RPC based on SCSMCC	PTAT and CTAT SAI-II SMQ LSQ SSI
Comparison Group (Section 05)	PTAT and CTAT SAI-II SMQ LSQ SSI	Traditional TLD Method	PTAT and CTAT SAI-II SMQ LSQ SSI

This design treats both units of ‘physical’ thermodynamics and ‘chemical’ thermodynamics in a time interval of one month. The PTAT represents Physical Thermodynamics Achievement Test. And CTAT represents Chemical Thermodynamics Achievement Test. RPC represents the constructivist conceptual change approach, which I developed by merging two other conceptual change approaches, and is called method of ‘Reasoned Persuasive Collaboration’. The two other conceptual change approaches used are taken from a class of pedagogical approaches known as ‘Critical-Analytic Pedagogies (CAPs)’. They are ‘persuasive pedagogy’ and ‘collaborative reasoning’. By merging these two, I created RPC which suits the purpose of my research, that is, testing the SCSMCC integrated model of conceptual change. TLD represents ‘Traditional Lecture-Demonstration’ method. SAI-II refers to the revised ‘Science Attitude Inventory’ and SMQ refers to ‘Science Motivation Questionnaire’. LSQ refers to ‘Learning Strategies Questionnaire’ scale and SSI represents the domain general ‘Study Skills Inventory’.

In a representational symbolic form, the quasi-experimental design is given as follows:

$$\begin{array}{l}
 N \ O_1 \ X \ O_2 \\
 N \ O_1 \ C \ O_2
 \end{array}$$

Here N shows the non-randomness of group selection which is implicit in quasi-experimental design. The X stands for experimental group which receives the treatment (RPC) based on SCSMCC. The C represents the comparison group which does not participate in the experimental treatment. O₁ (for both groups) represents the pre-test and pre-administration of questionnaires. And O₂ (for both groups) represents the post-test and post-administration of questionnaires. The O is taken from the first letter of the word 'Observation' in experimental research.

2.2.2 The Qualitative Design

As stated earlier, qualitative methods are useful for studying a limited number of cases in depth and are also useful for describing complex phenomena. It helps to identify contextual and setting factors as they relate to the phenomena of interest. And also determines causes of a particular interest. Qualitative methods are complementary to quantitative methods. And their synergetic effect is sought in this research. The qualitative methods used are: (1) interview with students regarding their conceptions of 'physical' and 'chemical' thermodynamics. Five grade 12 students (S₁, S₂, S₃, S₄ and S₅) were asked about their conceptions of thermodynamics on various topics. Students S₄ and S₅ were selected from the experimental group, students S₁ and S₂ were selected from the comparison group, and student S₃ was selected from a section outside the two groups. Two curriculum specialists, one for Chemistry and another one for Physics were interviewed regarding current status of secondary school science curricula. (2) Supervisors observations of the treatment in both physical thermodynamics (10 lessons) and chemical thermodynamics (12 lessons). The supervisors used observation protocols/checklists which is shown in Appendix H and used some summary space for their inspection of how the treatments were conducted. The summary data for each unit indicates the sources/causes of the outcome in the variables of quantitative part. Each lesson lasts 40 minutes and is four times a week. The maximum treatment period for each of the units is one month. An observation protocol and semi-structured interview schedules were used to collect data. The interview was tape-recorded, transcribed and reflected on and, the selected and voluntary, students and curriculum specialists were addressed using their coded/pseudo names. (3) Documentary analysis (rating form shown in Appendix G) is used to check the current status of grade 12 curriculum guides, teacher guides, and text books for both chemistry and physics subjects in order to substantiate results found from the treatments.

2.2.3 The Rationale for Using Mixed Methods Design

In mixed methods design, we include a qualitative phase and a quantitative phase in an overall research study. Mixed research involves a cyclical, recursive, and interactional process. Words, pictures, and narrative can be used to add meaning to numbers. And numbers can be used to add precision to words, pictures, and narrative. In mixed methods design, a researcher can use the strengths of an additional

method to overcome the weaknesses in another method by using both in a single study. It can also provide stronger evidence for a conclusion through convergence and corroboration of findings (Onwuegbuzie and Teddlie's(2003)). And it can add insights and understanding that might be missed when only a single method is used. It can also be used to increase the generalizability of the results. Qualitative and quantitative research used together produce more complete knowledge necessary to inform theory and practice. The time order decision taken in this research is concurrent, the quasi-experimental, non-equivalent groups design is dominant design for this research and the qualitative part plays the supporting role for the study. According to Onwuegbuzie and Teddlie's(2003), the *five major purposes or rationales* for conducting mixed methods research are:

- (1) *triangulation*-seeking convergence and corroboration of results from different methods and designs studying the same phenomenon,
- (2) *complementarities*-seeking elaboration, enhancement, illustration and clarification of the results from the other method,
- (3) *Initiation*-discovering paradoxes and contradictions that lead to a re-framing of the research question,
- (4) *Development*-using the findings from one method to help inform the other method,
- (5) *Expansion*-seeking to expand the breadth and range of research by using different methods for different inquiry components.

The mixed methods research process model incorporates Onwuegbuzie and Teddlie's (2003) *seven-stage conceptualization of the mixed methods data analysis process*:

- (a) *Data reduction*-reducing the dimensionality of the qualitative data (ex., through explanatory thematic analysis, memoing) and quantitative data (ex., through descriptive statistics, exploratory factor analysis, cluster analysis). In this research, quantitative data are reduced to 'gain scores' and 'total scores'. The mean 'gain scores' and the mean differences of 'total scores' are the reduced data in the quantitative part of the study and observational, interview, and documentary analysis are reduced using percentages, thematic analysis, transcription and reflection.
- (b) *Data display*-involves describing pictorially the qualitative data (ex., by matrices, charts, graphs, networks, lists, rubrics and venn diagrams) and quantitative data (ex., by tables and graphs). In this research the gain scores showing the changes in the variables of the study were displayed in tables while differences in total scores were reported in bar graphs. The gain scores and the total scores complement each other in the quantitative part of the study. A person interested in gain scores should refer to the tables and a person interested in total scores should refer to the graphs as they are representing different pictures of the same reality. The gain scores are simply the differences between post-administration of tests or questionnaires total scores and pre-administration of same tests or questionnaires total scores.

(c) *Data transformation*-quantitative data transformed (converted) into narrative data that can be analyzed qualitatively (i.e., qualitized) (Tashakkori and Teddlie, 1998) and qualitative data are converted into numerical codes that can be represented statistically (i.e., quantized) (Ibid). In this research I interpreted quantitative data and analyzed it qualitatively and quantized some of the qualitative data such as treatment observations for concise interpretations.

(d) *Data correlation*-involves the quantitative data being correlated with the qualitative data or the qualitative data being correlated with the quantitative data. Supervisors' observational data and student interviews are correlated with quantitative data in Chapter 8. Documentary analysis of text books, curriculum guides, and teacher guides are used to see the context of the research and are reported in chapter three.

(e) *Data consolidation*-both quantitative data and qualitative data are combined to create new or consolidated variables or data sets.

(f) *Data comparison*-involves comparing data from the qualitative and quantitative data sources.

(g) *Data integration*-characterizes the final stages whereby both quantitative and qualitative data are integrated into either a coherent whole or two separate sets (i.e., qualitative and quantitative) of coherent wholes. In Chapter 8, some of the qualitative data and quantitative data are integrated to provide an overall picture of the study.

(h) *Legitimization of Data*-assessing the trustworthiness of both the qualitative and quantitative data and subsequent interpretations. That is, checking for sources of invalidity.

The above mentioned rationales and data analysis processes are, therefore, utilized in this study.

2.3 Variables of the Study

The variables used in the non-equivalent group's quasi-experimental design are presented in what follows. The major independent variable of the study is: instruction based on constructivist conceptual change approach of SCSMCC as integrated model accompanied by RPC method. The other independent variables of the study are: gender, ability groups, attitude towards science, science motivation, students' perception on learning strategies, and study skills. The dependent variable is students' achievement in thermodynamics. A causal relationship between the independent variables and the dependent variable has been established as the study is dominantly quasi-experimental. To minimize the error variance of the situation of a single experiment in which the effect could be due to chance, I repeated the quasi-experiment in an interval of one month in a closely similar context in which thermodynamics is applied.

2.4 Formation of Groups

This study involves 104 12th Grade students (43 male and 61 female) of sections 05 and 06 of Bole Secondary and Preparatory School. The two sections were selected purposely as the teacher who agreed

to participate for the treatment of Grade 12 Physics unit one (Thermodynamics) was assigned by the school to these sections in addition to others. On preliminary evaluation of the sections the treatment teacher handled, the two sections 05 and 06 were found to exhibit almost similar ability distributions regarding their previous year's total average scores. The Physical Thermodynamics unit one was taught by the same teacher in the October of first semester of 2010/2011 academic year. One month after the termination of Physical Thermodynamics unit treatment, same section of students were exposed to similar treatment on unit three of Chemistry which is about an almost similar topic of Chemical Thermodynamics. These repeated measurement of one item on several occasions, can replace the issues of 'increasing sample size', 'randomizing samples' and 'randomizing experiments'. Although the randomized controlled trial is generally considered to have the highest level of credibility with regard to assessing causality, researchers often choose not to randomize the intervention for one or more reasons: (1) ethical and legal considerations, (2) difficulty of randomizing the subjects, (3) difficulty to randomize by locations, (4) small available sample size. Randomization is beneficial because on average it tends to evenly distribute both known and unknown confounding variables between the intervention and control group. However, when the sample size is small as in experiments, randomization may not adequately accomplish this balance. The above two sections were assigned randomly to experimental and control groups using the simple lottery method. As a result of the draw, section 05 was assigned to the comparison group and section 06 was assigned to the experimental group. This way I matched participants and non-participants on a key trait of performance before the treatment started. The term 'comparison' is used instead of the term 'control' as 'control' is very difficult in quasi-experiments. Many people acknowledge that the term 'control' is only theoretical and not practical in research of social nature.

However, except for lack of treatment, the comparison group is similar to the treatment group composition and has characteristics that the research base demonstrates that are important relative to the intended outcomes of my research. The experimental group is similar in every sense to the comparison group, but in addition, one independent variable is being tested by the experiment. Stronger assumption on comparability of the two groups can replace randomness as a technique of ensuring equivalence and normal distribution. Randomness is used when there is reason to believe that the units are not completely equivalent.

In the absence of physical control, as in physical sciences true experiments, we use statistical control of ANCOVA by subtracting the initial differences between the two groups in their pre-tests. I, therefore, matched, balanced and made comparable the two groups to reduce non-equivalence or initial difference

between the two groups. It is thus assumed that if differences occur after treatment, it is simply due to the new teaching strategy employed based on SCSMCC as holistic model of conceptual change. In statistical control if we imagine that any post-test or post-administration difference between the groups is due to differences in the pre-test or pre-administration, the ANCOVA F test evaluates whether the means on the dependent variable, adjusted for differences on the covariate, differ across levels of a factor. ANCOVA allows us to adjust the achievement scores based on the relationship between pre-test results or pre-administration scores and achievement scores. We can then determine if comparison and experimental groups still have different Thermodynamics achievement scores after making the adjustment.

The class size of experimental group was 53 (26 male and 27 female) and the class size of comparison group was 51 (17 male and 34 female). Therefore, some students who were consistently outliers and those who did not attend the class regularly were eliminated as sources of data. Thus, out of 104 students in the two sections only 80 of them, 40 from each section, were used as reliable sources of data. Therefore, the data used in this research for analysis is taken from 40 (18 female and 22 male) students participating in instruction based on constructivist conceptual change approach (RPC) and the other 40 (24 female and 16 male) students participated in traditionally designed Lecture-Demonstration Method.

During the treatment, the Physical Thermodynamics and Chemical Thermodynamics units were covered as part of the regular classroom schedule for Grade 12 physics and chemistry in the first semester of 2010/2011 academic year. Each of the lessons took 40 minutes and four times a week. Both groups, for each of the units, were instructed by their school assigned subject teachers.

2.4.1 The Experimental Group

This is a non-randomized intervention group. As in randomized trials, quasi-experiments aim to demonstrate causality between an intervention and an outcome. Quasi-experiments usually suffer from 'regression to the mean' which is a statistical phenomenon of wrongly concluding that an effect is due to the intervention when in reality it is due to chance. To minimize this risk, I repeated the treatment of the same experimental group in two similar contexts in which thermodynamics is applied. One is in 'Physical Thermodynamics' unit one of Grade 12 Physics syllabus and the other after an interval of one month in 'Chemical Thermodynamics' unit three of Grade 12 Chemistry. If the effect upholds on these two occasions, it is highly unlikely that the effect is due to chance.

The class size of experimental group was 53 (26 boys and 27 girls). Because of attrition and outliers only 40 (18 female and 22 male) of them were included in the study. This group was divided into three ability groups based on their 11th Grade final exam scores. The purpose of this division was to form mixed

ability groups in preparation for small group discussion phase of the SCSMCC model in which the method of 'Reasoned Persuasive Collaboration' is applied. The mixed ability groups were organized in the following proportion: one low achiever (25%), two average achievers (50%), and one high achiever (25%). The seating arrangement was adjusted accordingly in preparation for the intervention. Orientation was given to the students in this group about the six phases of SCSMCC as integrated model of conceptual change and the accompanying RPC method. Students were not aware that this was meant for experimental investigation. The six phases of SCSMCC as comprehensive model using the RPC method were consistently applied in both Physics and Chemistry units in which Thermodynamic concepts were applied. Pre-tests or pre-administrations of tests and questionnaires were conducted just before the treatment began and also post measurements were taken just after the treatments.

2.4.2 The Comparison Group

The class size of comparison group was 51(17 male and 34 female). Because of attrition and outliers only 40(24 female and 16 male) of them were included in the study. This is the group which did not receive the intervention. This group was selected because of its similarity with the experimental group but only after the lottery draw. Students in this group were not initially divided into ability groups based on their 11th grade final total score results as group discussion was not the method applied. The method used was not guided by a model as in the intervention. The only difference between experimental and comparison groups was the independent variable of treatment in experimental group.

2.5 The Treatment

The treatments of both physical thermodynamics unit and chemical thermodynamics unit are presented below. The Contents, Lesson Plans, and Methods for 'Physical Thermodynamics' and 'Chemical Thermodynamics' are described in this section. My integrated model uses a blended pedagogical method of '**Reasoned Persuasive Collaboration (RPC)**'. This method or instructional strategy is a combined method from two other methods recommended for conceptual change instruction. These are 'persuasive pedagogy' and 'collaborative reasoning' methods. Persuasive pedagogy requires that teachers and students critically and analytically evaluate prior beliefs and knowledge through the use of reason, evidence, and justification. In this approach, teachers select materials that require students to take position, and the justification of that position is of central concern during instruction. Collaborative reasoning employs discussion to foster students' critical reading and thinking about text as part of instruction and uses the idea of reasoned argumentation as a model of critical thinking and encourages students to use reasoned discourse as a means for choosing among alternative perspectives on an issue. Both methods require students adopt a position on the conceptions and validate them and there by overcome their misconceptions. I, therefore, felt that the two methods can be combined to teach the

experimental group and the traditional lecture–demonstration method can be used to teach the control group. I also tried to look into the implications of this model of conceptual change for curriculum design and development. The contents of heat and thermodynamics, at Grade 12, Physics unit one and the contents of Chemical Thermodynamics, at Grade 12, Chemistry unit three are taught to the same groups in an interval of one month. This is aimed at rechecking the validity of the model on two different occasions and also checks whether transfer of knowledge has occurred from Physical Thermodynamics to Chemical Thermodynamics.

2.5.1 The Contents for Grade-12 ‘Physical Thermodynamics’ and ‘Chemical Thermodynamics’

Grade 12 Physics syllabus lists the following content for unit one on thermodynamics: Laws of thermodynamics, thermodynamic processes, work and heat in thermodynamic processes, kinetic theory of gases, heat engines and reversible and irreversible processes are the major themes and concepts.

Grade 12 chemistry syllabus lists the following content for unit three of chemical thermodynamics: Common thermodynamic terms, first law of thermodynamics and some thermodynamic quantities, thermo chemistry, entropy and the second law of thermodynamics are the major themes and concepts.

In the experimental group students are required to construct this knowledge without taking it for granted. Ten lesson plans each lasting for forty minutes were developed by me for ‘Physical Thermodynamics’. The treatment was conducted in October 2010 and it lasted for a month. One of the lesson plans on ‘*thermal equilibrium and definition of temperature*’ will be shown in the following. Fully developed lesson plan one for physical thermodynamics and lesson plan two for chemical thermodynamics are shown in Appendix I. Nine other lesson plans were developed for physical thermodynamics unit and eleven similar lesson plans were developed for ‘Chemical Thermodynamics’ and the lessons were conducted in October and December 2010, respectively.

In the comparison group students were required to take these contents for granted. Ten traditional lesson plans each lasting for forty minutes were developed. The students were taught physical thermodynamics in October 2010 and it lasted for a month. One of the lesson plans on ‘*thermal equilibrium and definition of temperature*’ and one of lesson plans, out of 12 of them, on ‘Common Thermodynamic Terms’ of ‘Chemical Thermodynamics’ are shown in the following. All other 11 lesson plans were developed in a similar manner.

The SCSMCC as comprehensive model can be conceptually understood as a model which combines individual cognitive efforts with socio-cultural interaction and their interplay can evolve in conical-spiral

manner in the process of learning. The SCSMCC as comprehensive model can be labeled as 'the cognitive and socio-cultural conceptual restructuring model'. Yager (1991) proposed a constructivist teaching strategy with the following phases: (1) Invitation, (2) Exploration, (3) Proposing explanations and solutions, and (4) Taking action. Similarly, Driver and Oldham (1986) developed a model for constructivist teaching sequence which has five phases: (1) Orientation, (2) Elicitation, (3) Restructuring, (4) Application, and (5) Review. Chapter four of this thesis shows other models of conceptual change as well. Constructivists believe that knowledge cannot be transferred into the student or itched on to him/her as a blank slate or a cup to be filled. Traditional teaching strategies consider the student as a passive recipient of knowledge. Constructivists', however, believe that knowledge is actively and personally constructed and socially mediated. Learners form, elaborate and test new knowledge until they become satisfied. Learning occurs by changing and organizing cognitive structure.

2.5.2 Lesson Plan (40 minutes) for 'Physical Thermodynamics'

Treatment/Experimental Group

Here, rather than showing the full format of the lesson plan which is shown in the Appendix I, I will try to discuss the most important elements of the lesson for the above mentioned topic.

Phase 1 of SCSMCC as integrated model (Engaging the Door Keepers-Motivation, Affection and Socio-cultural Factors): Teacher introduces the topic of the lesson while at the same time motivating and arousing their curiosity and interest in the topic. The RPC strategy used was based on SCSMCC as comprehensive model of conceptual change. In this strategy the teacher starts the lesson by motivating and nurturing interest in the particular topic. For example, by telling a history of the particular scientist who contributed to the topic under study, some self-efficacy stories from the teacher or a capable peer etc. This should be done in a short and precise manner for the purpose of not wasting class time. Teacher writes the two categories of valid and invalid conceptions side by side on the blackboard and asks students to decide through argument, evidence and justification as to which category they think is the scientifically correct and valid conception (5 minutes). The word "misconception" or invalid conception refers to: (1) students' mistaken answers to a particular situation, (2) students' ideas which cause mistaken answers about a particular situation, and (3) students' beliefs about how the world works different than that of the scientists (Dykstra, Boyle and Monarch, 1992). If a student holds misconceptions, these misconceptions interfere with subsequent learning. For this lesson the categories presented were:

Category one

1. Heat has a property of matter or substance
2. Like heat, temperature is a property of the Material from which a body is made
3. If material A is in thermal equilibrium with Material C and material B is also in equilibrium then A and B are not in equilibrium

Category two

1. Heat is a flow of energy between different substances
2. Temperature is measured as a measure of an average kinetic energy of molecules and it is not an intrinsic property of a Substance
3. If material A is in thermal equilibrium with Material C and material B is also in equilibrium With C, then A and B are in equilibrium

The creation of categories is dictated by the RPC method which requires teacher's provision of a learning material on which learners take position after critically analyzing the material. In this lesson plan the incorrect category is category one. Chapter 5 of this thesis discusses many of the misconceptions reported in Physics and Chemistry Education researches.

Phase 2 of SCSMCC as integrated model (Initial Personal Thinking): Allow students to think individually for 3 minutes. They reorganize their thinking about their background knowledge associated with the topic and identify points of difficulty. And take position individually as to which category they think is correct. The Initial Personal Thinking (IPT) phase is actually an exploratory personal discovery phase. Involving students in discussions without some personal thinking results in wastage of time. Students have to learn to think before they actually speak their minds. This should be a good practice well into the rest of their life. Haidar and Abraham (1991) found that formal reasoning and pre-existing knowledge play an important role in the development of students' conceptions.

Phase 3 of SCSMCC as comprehensive model (Small Group Discussion): Teacher prompts the students to share ideas and discuss with pre-planned nearest neighbor mixed ability and gender discussion groups in the process of restructuring their conceptions and come to a group consensus and select a spokesperson for their position's presentation (5 minutes).

Phase 4 of SCSMCC as comprehensive model (Whole Class Discussion): Each group participates via their spokesperson in whole class discussion and report their position, doubts, and conceptions supported by evidence, reasoning and justification in the process of restructuring their conceptions. The teacher facilitates the process of whole class discussion, clarifies on doubts and drives the learners towards whole

class consensus (7 minutes) as to which category is correct and why it is so. The teacher needs to sharpen and focus the discussion by identifying direction, sorting ideas for relevance, and focusing on key points. In the discussions, conceptual restructuring is expected to happen.

Phase 5 of SCSMCC as holistic model (Individual Critical Reflection): Students individually look back and critically reflect on and evaluate all what has been discussed, thought, what went wrong, and how it was corrected and any lessons to be drawn from this learning experience. The teacher provides, in the mean time, notes on correct scientific conceptions and explains why they differ from our intuitive every day conceptions of thermodynamic phenomena and give challenging conceptual questions and problems which require both conceptual and procedural understandings (10 minutes). Students need to dig deeper by utilizing full-spectrum questioning, making connections, and honoring multiple perspectives raised during discussions. Students are required to question existing beliefs and assumptions. This individual reflection phase puts conceptual restructuring on a sound basis.

Phase 6 of SCSMCC as unified model (Deep Understanding): demonstration of deep understanding by answering challenging conceptual questions and by solving problems which resemble real life situations. Application of his/her knowledge in solving problems demonstrates his/her deep understanding of the topic or learning task (10 minutes). This phase reveals whether conceptual change has really occurred. If the change did not occur in the classroom or initial cycle, then the next cycles should be tried by way of tutorials or home work/ assignment/ project or a group study under the guidance of capable peer or adult-expert, and so on. The spiral in the model bridges individual and social formation of concepts in a continuous manner and shows that learning is a life-long process.

The six phases of the SCSMCC as unified model comprise one cycle of the spiral. If the learner did not achieve deep understanding in the initial cycle s/he can continue outside the classroom by initiating similar cycles.

2.5.3 Lesson Plan (40 minutes) for 'Chemical Thermodynamics' **Treatment/Experimental Group**

Here, rather than showing the full format of the lesson plan which is shown in the Appendix I, I will try to discuss the most important elements of the lesson for the above mentioned topic.

Phase 1 of SCSMCC as integrated model: Teacher introduces the topic of the lesson while at the same time motivating and arousing their curiosity and interest in the topic. For example, by telling a history of the particular scientist who contributed to the topic under study, some self-efficacy stories from the

teacher or a capable peer etc. This should be done in a short and precise manner for the purpose of not wasting class time. The students should use initial active listening to grasp the task of the day and the teacher should ascertain that s/he has full control over the class. The teacher writes the two categories of valid and invalid conceptions side by side on the blackboard and asks students to decide through argument, evidence and justification as to which category they think is the scientifically correct and valid conception (5 minutes). One category contains normative ideas or scientifically valid conceptions. A parallel category contains, in one to one correspondence with normative conceptions, non-normative ideas or what is known as well-researched common misconceptions found from literature on the topic of the lesson. The transition from non-normative to normative ideas can be abrupt or evolutionary. For this lesson the categories presented were:

Category one

1. *Spontaneous processes occur under external influence*
2. *Intensive properties are properties which do not depend on the amount of matter*
3. *In isothermal process, $\Delta T \neq 0$ but $Q = 0$*
4. *In adiabatic process, $\Delta T = 0$ but $Q \neq 0$*

Category two

1. *Spontaneous processes do not occur under external influence*
2. *Intensive properties are properties which depend on the amount of matter present*
3. *In isothermal process, $\Delta T = 0$ but $Q \neq 0$*
4. *In adiabatic process, $\Delta T \neq 0$ but $Q = 0$*

A list of common-misconceptions was given to teachers along with how to categorize them and make them a starting point for their lesson. Only two to three common misconceptions and correct conceptions paralleling them were presented in the lesson plan. This does not mean that students' misconceptions are ignored and only predetermined ideas are entertained nor a list of two to three common-misconceptions is exhaustive. It is only to cope with time constraint and to focus the lesson and serve as a starting point for reasoned persuasive collaboration. Preparing the material on which the students are asked to take position is the task of the teacher in CAPs strategies. Students are required to think and reason out, argue based on evidence and justify that their position is correct in the process of persuading others in the group/class. The prior knowledge of the students is organized, patterned and used in giving meaning to the learning task at the Initial Thinking Phase and subsequently made explicit during discussion phase. This helps the teacher to identify students' learning difficulties associated with the topic and properly address them.

In this lesson plan the incorrect category is category one. An example lesson plan two is shown for grade 12 unit three: Chemical Thermodynamics in Appendix I. Chapter five of this thesis discusses many of the misconceptions reported in Physics and Chemistry Education researches. Phases two to six are similar to those of 'Physical Thermodynamics'. The six phases of the SCSMCC as holistic model comprises one

cycle of the spiral. If the learner did not achieve deep understanding in the initial cycle s/he can continue outside the classroom by initiating similar cycles. In all of the phases conceptual restructuring and conceptual change is expected to happen.

In the above lesson plan for experimental group, it is implicitly shown that a method derived from a class of pedagogical approaches known as Critical-Analytic Pedagogies was used. Two of most commonly used methodologies from this class were 'Persuasive Pedagogy' and 'Collaborative Reasoning'. I created a hybrid method seeking the synergetic effect of the above two methods which I called '*Reasoned Persuasive Collaboration*' and it was in action in all phases of the SCSMCC as integrated model. Learning in this way is taken as interplay of individual cognitive component and of social interaction. And to show the continuity of such interplays, the conical-spiral configuration is used. The above lesson plans are constructivist or conceptual change plans in which the teacher acts as a change agent or facilitator and in which the learner is active participant.

2.5.4 Lesson Plan (40 minutes) for 'Physical Thermodynamics' and 'Chemical Thermodynamics' of Comparison Group

Here, rather than showing the full format of the traditional lesson plan, I will try to discuss the most important elements of the lesson for the above mentioned topic. The format is currently used in many secondary schools in Ethiopia.

Introduction (5minutes): the teacher introduces the lesson on 'thermal equilibrium and definition of temperature' of 'Physical Thermodynamics' by explaining the objectives of the topic, establish connection with background knowledge by asking probing questions and show the topics which are going to be covered. Similarly, the teacher introduces the lesson on 'Common thermodynamic terms' of 'Chemical Thermodynamics' by explaining the objectives of the topic, establish connection with background knowledge by asking probing questions and show the topics which are going to be covered.

Presentation (30 minutes): the teacher discusses in depth the contents but with little or no learner participation. The students sit, listen, watch and take notes. The teacher supports his/her presentation with simple demonstration experiments or teaching aids. S/he showed work-out numerical examples with less emphasis on conceptual understanding and more emphasis on procedures of problem solving. The students rarely question what they are learning and they can take whatever the teacher says for granted.

Stabilization (5 minutes): teacher summarizes and highlights the most important points and asks questions to know whether s/he has achieved the objectives of the lesson. The teacher at last provides home tasks as

exercise or drill. This is the behaviorist or positivist lesson plan in which the teacher is the authority and source of all know how and know what. The learners are passive recipients of information.

The method used is the Traditional Lecture-Demonstration (TLD). In the initial part of the lesson, the teacher lectures about the content and this is followed by simple demonstration experiments and/or teaching aids for the purpose of demonstrating the laws, theories, and concepts.

2.6 Teacher Characteristics

Two teachers were involved in this research. Teacher T_1 participated in teaching Grade 12 Physics unit one: '*Physical Thermodynamics*' using two methods for the selected groups as described above. He holds MSc degree in Physics from Addis Ababa University. He had six years teaching experience at secondary school level and a one year teaching experience at Gondar University. For some reason he left his teaching post at Gondar University and preferred to work at school level. His Physics knowledge was very good except for some dissatisfaction regarding his salary. He conducted the treatment very well as I trained him in SCSMCC as integrated model and RPC method. I prepared 10 lesson plans for him and he executed it accordingly.

Teacher T_2 participated in teaching Grade 12 Chemistry unit three: '*Chemical Thermodynamics*' using TLD for the comparison group and RPC based on SCSMCC integrated model for the experimental group. She was a 'Lab' school student of Haile Selassie I University and holds a BSc degree in Chemistry. She had more than twenty years of teaching experience. She was very serious as a teacher and very much respected by her colleagues and students. She was very helpful to me and very much receptive of my training on RPC method based on SCSMCC as integrated model of conceptual change. Her Chemistry knowledge was very good. I prepared 12 lesson plans for her and she executed her duties accordingly. The higher qualifications of teacher T_1 was compensated by long years of experience of teacher T_2 . There was no choice except to accept such matching of teacher ability as the school assigned the two teachers for sections 05 and 06 of Grade 12 students to teach their respective subjects.

2.7 Supervisors of the Treatments

Supervisors' lesson observation protocol for the treatment group was adapted from internet sources and prepared by myself to suit the context of my research and training was given to Grade 12 Physics supervisors on how to follow the lessons and fill the protocols in late September of 2010. They all completed the observation protocol after supervision and handed them over to me. The same observation protocol was used to observe similar treatment in Grade 12 Chemistry. Training was given to Grade 12 Chemistry supervisors in late November of 2010. In both cases the supervisors were selected on voluntary

basis from their respective departments and fields. I received all 12 observation protocols at the end of second treatment period. I occasionally followed how both the treatment and comparison groups were taught and I confirmed that things went as planned.

2.8 Instruments of Data Collection

The following are instruments used for data collection.

2.8.1 Physical Thermodynamics Achievement Test (PTAT)

This test was developed by me using standard questions and problems from the literature. The content of this test was determined by examining text books, instructional objectives of unit one of Grade 12 Physics syllabus, some fragmented conceptual tests found on the internet which fits Grade 12 thermodynamics content, and related literature on students' conceptions and misconceptions. The list of students' conceptions/normative ideas and misconceptions/non-normative ideas is shown in Table 5.1 of Chapter five of this thesis. This test had two parts. The first part consists of 27 multiple choice conceptual questions on thermodynamics, with misconceptions used as distracters along with valid conceptions. The second part consisted of three workout procedural questions with two or three sub-questions for each item. Most of the test questions were taken from standard questions found on the internet but some of them are modified. The test-retest reliability of this test was found to be 0.781. The content and face validities of this test were established by experts in pure physics, physics education, secondary school physics teachers, and finally by the advisor of this research (See Appendix A for this test).

2.8.2 Chemical Thermodynamics Achievement Test (CTAT)

This test is also developed by me using standard questions and problems from the literature and with some help from chemistry experts and teachers. The content was also determined by examining text books, instructional objectives of unit three of Grade 12 Chemistry syllabus, commercial books on secondary school chemistry, and some conceptual questions found from the internet which fits Grade 12 chemical thermodynamics content, and related literature on students' conceptions and misconceptions. The list of students' conceptions/normative ideas and misconceptions/non-normative ideas is shown in Table 5.2 of chapter five of this thesis. This test has two parts. The first part consists of 27 multiple choice conceptual questions on thermodynamics, with misconceptions used as distracters along with valid conceptions. The second part consists of three workout procedural questions with two or three sub-questions for each of the items. Most of the test questions were taken from standard questions but some of them are modified. The test-retest reliability of this test was found to be 0.743. The content and face validities of this test were established by experts in pure chemistry, chemistry education, and secondary school chemistry teachers, and finally by the advisor of this research (See Appendix B for the test).

2.8.3 Revised Scientific Attitude Inventory (SAI-II)

The first version of SAI-I was reported over 40 years ago (Moore & Sutman, 1970). Twelve position statements, six opposing positive and negative statements, were developed for universe of content, namely, attitude towards Science. The position statements were intended to represent both intellectual and emotional attitudes. The content validity of this scale was claimed on the basis of the evaluation of the panel of judges from science educators, practicing scientists, and liberal arts science professors. It was also field-tested and revised. In SAI-II, gender biased language was eliminated and instead of 60 items of SAI-I, a 40 item SAI-II was developed. Upon its field-testing, a split-half reliability of 0.805 was reported (Moore et al., 1997).

In this research, a common scientific attitude inventory is used instead of physics and chemistry attitude inventories. If we use the subject wise inventories, we may encounter difficulty in comparing attitude towards the subjects and hence a common science attitude inventory scale was used (See Appendix C for SAI-II scale).

2.8.4 Science Motivation Questionnaire (SMQ)

In general, motivation is the internal state that arouses, directs, and sustains goal-directed behavior. In particular, motivation to learn refers to the disposition of students to find academic activities relevant and worthwhile and try to derive the intended benefits from them (Brophy, 2004). Six motivational components have been linked to learning science and have been included in SMQ. First, there is *intrinsic motivation*, which involves learning science for its own sake (Eccles et al., 2006). This is what Dole and Sinatra (1998) called in their CRKM model, *need for cognition* or *curiosity*. Second, there is *extrinsic motivation*, which involves learning science as a means to an end (Mazlo et al., 2002). This is *outcome oriented* motivation. Third, there is *personal relevance*, which is the relevance of learning science to students' goals (Cavallo et al., 2003). Fourth, there is *self-determination*, which refers to the control students believe they have over their learning of science, which is a kind of metacognitive control (Black & Deci, 2000). Fifth, there is *self-efficacy*, which refers to students' confidence that they can achieve well in science (Lawson et al., 2007). And six, there is *assessment anxiety*, which is the debilitating tension some students experience in association with grading in science (Parker & Rennie, 1998).

Glynn and Koballa (2006) developed the 30-item Science Motivation Questionnaire in its present form. George and Mallery (2006) computed the reliability of this scale and found Cronbach coefficient alpha equal to 0.91, which was considered "excellent", indicating that 91% of the variance of the total scores on this questionnaire can be attributed to systematic variance (See SMQ scale in Appendix D).

2.8.5 Learning Strategies Questionnaire (LSQ)

This questionnaire is developed by Abrami and associates (2007) and its reliability was found to be 0.834. This questionnaire was used because students would have an opportunity to give feedback on their teaching and learning experiences. This provides students' perceptions of effective teaching in secondary schools. Twenty close-ended Likert scale questions were used to match the learning strategies questions asked of teachers on a parallel teacher questionnaire developed by Abrami and associates(2007)(See the LSQ scales in Appendix E).

2.8.6 Study Skills Inventory (SSI)

Students need to assess their study skills and refine them for better performance. The way they study determines the outcome and their conceptual and procedural understandings. The SSI was developed by Congos (1999). The SSI was used to measure the study skills level of students. The SSI is a five-point Likert type scale that consists of 51 items. As it first appeared on a self-help book for the students, SSI has had no evidence for statistical validity and reliability--at least as far as the literature the researcher surveyed shows. Both the reliability calculations and validity studies were conducted by Credè and Kuncel (2007), found the Cronbach reliability coefficient for Study Skills Inventory as 0.71. This variable was considered as one of the confounding variables that undermine the results of this research, and therefore, it was included in the study to see its effect as a covariate (See Appendix F for this scale).

2.9 Validity of the Instruments

The instruments were content and face validated by the advisor, colleagues in science and mathematics education, by school teachers, etc. Some of the instruments were standard scales with reported validation procedures while some of the scales were standard but as such their reliabilities were not reported by their original developers but by researchers in the field. This statement is valid as far as the literature I have reviewed is concerned. On all of them, opinions of experts were taken into account, in order to make the instruments fit for the purpose for which they are required. Those for which reliability coefficients were already reported in the literature and therefore standardized by their developers and used extensively by other researchers are accepted as valid ones. The reported reliabilities are also quoted. Four such instruments were 'the Scientific Attitude Inventory-II,' the 'Study Skills Inventory', 'the Science Motivation Questionnaire' and 'Learning Strategies Questionnaire'. The questions in these instruments are general and are not context dependent. Therefore, they can be used in the Ethiopian context with no changes to their content.

All the scaled questionnaires were used as they appeared in their original form. All of the instruments, including the tests developed by the researcher, proved valid and reliable and the reliability of all of the instruments fall in the range of 0.71 to 0.92. According to Ozdamar (1997), reliability between 0.80 and

1.00 indicate that the instrument is highly reliable and can be used for the purpose of the study. All the scaled questionnaires except 'Study Skills Questionnaire' fall in this range. But the tests developed by me slightly fall outside this range. The physics test was very close as its test-retest reliability is 0.78. For the chemistry test the test-retest reliability was still lower and is 0.74.

As the coefficients of reliability calculated by including all of the items is high enough to serve the purpose, it was not found important to modify or eliminate some of the items. Except for the tests, the other scales are kept as they are context-independent and general.

The school community, where the study was conducted, is highly cooperative. As a result the instruments were administered by providing some explanation on the procedures to be used in item scoring. It took on the average 20 minutes to fill the scales and answer questions by each individual learner/respondent. The instruments, most of the time, were collected soon after they were duly filled and questions/problems are answered/solved.

The interview protocol, observation protocol, and documentary analysis rating scale were also content and face validated by my advisor, science and mathematics education experts, school teachers and curriculum specialists. Interview in semi-structured format is used to give room for maneuvering around learner conceptions of thermodynamics. The interview with each student lasted for 20-30 minutes on the average and those with the curriculum experts lasted about 40 minutes on the average. Two curriculum experts and five students were interviewed. For ethical reasons, the students and curriculum experts are addressed by their pseudonyms and/or a coding letter.

2.10 Strategy for Data Analysis

Normality test was conducted and t-test, one-way and repeated measures ANOVAs were selected for the achievement tests. For Likert scale questionnaires, the two groups were analyzed using their mean gain scores and the parametric tests were applied as all of them have five levels. For levels greater or equal to five ordinal variables can be considered as scale variables and normality test shows that parametric statistics can apply to all of them except for Kruskal-Wallis test that compares the three ability groups for students' perceptions of teaching learning strategies. For the achievement graphs ANCOVA is used to adjust the initial differences between the two groups. For the three ability groups one way ANOVA with Tukey post hoc test for physics test gain and two way ANOVAs as well as GLM Repeated Measures ANOVA are applied. Independent samples t-test (two-tailed) is used to determine the relative effectiveness of the two different instructional methods used to teach physical thermodynamics and chemical thermodynamics. Also independent samples t-test is used to see the difference in conceptual change with regard to gender. Independent samples t-test is used to compare comparison and

experimental groups regarding conceptual and procedural understandings as well. Paired samples t-test is used to compare physics and chemistry achievements for both groups. One-way ANOVA is used to see the variation of conceptual change with regard to the three ability levels. Cohen's effect size d (ES), and multiple linear regression were used to explain the contribution of the various variables for conceptual change. Normality tests and Levene's test of homogeneity of variances are used in each case of selection of statistical tests. Percentages are used to summarize classroom observation data. Interviews are quoted and reflected on. Interview data is finally coded, categorized, and generalized. Documentary analysis of curriculum guides, teacher guides and text books is rated by percentages and the documents are quoted and reflected on in a narrative style. The qualitative and quantitative results are then integrated to consolidate the research findings.

2.11 Assumptions and Limitations

2.11.1 Assumptions

1. There is no interaction between the groups
2. The teacher was not biased during the treatment
3. The tests/questionnaires were administered under standard conditions
4. The subjects answered the questions/problems in the instruments seriously and sincerely

2.11.2 Limitations

1. This study was limited to grade 12 students of Bole preparatory and secondary school sections 05 and 06 of the academic year 2010/2011
2. The results may not be generalized beyond secondary schools context
3. The results were limited to the units of physical thermodynamics and chemical thermodynamics

2.12 Conclusions

Pintrich and associates (1993) called for experimental, reliable behavioral measures, longitudinal and developmental research rather than correlational research which has more methodological rigor in conducting conceptual change research. The repeating of the quasi-experimental research design in two different but similar contexts helped me to put the result of testing the new SCSMCC on a sound and non-trivial basis. Figure 1.2 in chapter one depicts how this is done. This design helped me to arrive at a conclusion that the new model is context independent and stable. It also helped me to connect the conceptual change approach and knowledge transfer across contexts. Therefore, this research fulfilled the methodological rigor called for by Pintrich and associates (1993) for future conceptual change research.

CHAPTER THREE: LEARNING THEORIES AND CONTEXT OF THE RESEARCH

3.1 Introduction

In this chapter I will try to show the background information that led to the development of the SCSMCC and research findings that suggested its' importance. The review also shows doubts about bridging personal cognition with socio-cultural formation of concepts. Learning theories developed by Ausubel(1978), Piaget(1929, 1937, etc.), Vygotsky(1978), and Bruner(1960) have relevance for conceptual change learning and research. It is necessary to see the similarities and differences of these theories in order to justify their integration for the purpose of conceptual change learning and research. The two major variants of constructivism namely radical constructivism and social constructivism are discussed. The origin of learning as conceptual change in science education and the various theories of conceptual change such as knowledge-as-theory perspectives and knowledge-as-elements perspectives are discussed. The context of this research and lack of conceptual change strategies is discussed using documentary analysis of text books, curriculum guides, teacher guides. And a transcribed summary of interview with secondary science curriculum experts at the Ministry of Education just before the treatment was also presented.

3.2 Comparison of Behaviorism, Cognitivism and Constructivism

Behaviorism considers learning as an observable change in behavior. Learners observe, practice and receive information through reinforcement--praise, drill, and practice. Learning takes place through acquiring facts, concepts and skills. Behaviorism, and hence positivism, believes in a detached, objective observer of reality who has no influence on what is observed. There is no place for subjectivity. Teaching is viewed as a transmission of information and the behaviorist curriculum is content-loaded. Learners are required to master all of the content conveyed to them by the curriculum and the teacher. Learners are viewed as passive recipients of information and the teachers are viewed as sources of all know how and know what. Behaviorism was founded by researchers such as Thorndike(1932), Skinner(1953),etc.

Cognitivism, as theory of learning, explains the mechanism of information processing to produce learning. It tries to intellectualize the learner by changing his/her mental behavior. It looks into how information is processed from the sensory memory to working memory and to the long-term memory. The theory focuses on gaining and maintaining the learners' attention. After the attention is gained, then rehearsal and visuals are used to process the information in the memories and in cognitivism, learning mimics the human thought process. Piaget (1929, 1937, etc.) and Simon (1989a) were founders of cognitive learning theory. Cognitivism is not much different from behaviorism regarding student and

teacher roles. Teachers are the sources of all know how and know what and learners are passive recipients of information.

Constructivism is a theory that describes learning as learner's construction of knowledge. The theory focuses on understanding the information and learning is an active process of knowledge building. Vygotsky(1978) who is known for his zone of proximal development and Bruner(1957) who stated learning as an active process are founders of constructivist learning theory. Retrieving prior knowledge and collaboration help acquire new knowledge. The teacher serves as a facilitator of knowledge construction. Learners are in charge of their own learning. Learners investigate and solve problems.

3.3 Similarities between Learning Theories

Piaget's learning theory holds that children as well as adults use mental patterns or schemes to guide behavior or cognition and interpret new experiences or material in relation to existing schemes (Piaget, 1978). A new material can be assimilated when it fits with an existing scheme and accommodation happens when new material/information/message does not fit with an existing scheme. According to Ausubel (1978) new material/message or meaningful information is stored in networks of connected facts or concepts which Piaget called schemata. Information that fits an existing schema is more easily understood than that does not fit it. According to Vygotsky(1978), the cultural foundation of cognition is the presence of a "Zone of Proximal Development (ZPD)". The concept of ZPD refers to the existence of a zone for each individual learner bordered by one side by the developmental threshold necessary for learning and bounded on the other side by the upper limit of the learner's current ability to learn the material unaided (Vygotsky, 1978). Ausubel (1978) defined rote learning as "arbitrary, verbatim, non-substantive incorporation of new ideas into cognitive structure". It creates difficulties in patterns of recall, failure to notice associations, etc. If existing schema cannot explain new information, it is then necessary to change existing schemes or generate new one which is called Piaget's accommodation. The precondition for accommodation is disequilibrium, the state in which the new information does not fit an existing scheme. The balance of the cognitive system/equilibrium occurs when new schemes/structures should be developed or old ones modified until the new information is accommodated.

Vygotsky(1978) elaborated the dimensions of school learning using his concept of ZPD. And he noted that ZPD is "the distance between the actual development level, as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers". According to Piaget, existing schemes or prior cognitive structures largely determine opportunities for disequilibrium, and subsequent accommodation or conceptual change. According to Ausubel (1978), "prior knowledge or existing schemata are of central

importance if the learner is to meaningfully acquire new information or concepts". Novak (1988) asserts that meaningful learning occurs when new information is subsumed by existing relevant concepts and these concepts undergo further change and growth. The above theorists emphasized the importance of prior knowledge or existing cognitive frameworks for further learning. Especially, Ausubel made this very clear when he asserted that:

If I had to reduce all educational psychology to just one principle, I would say this: the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him/her accordingly (Ausubel, et al., 1978: p.iv).

Vygotsky(1978) noted that scientific (non-spontaneous) concepts which are taught in schools are abstract and general which the learner eventually relates his/her spontaneous (everyday/lay culture) concepts to scientific concepts as a part of system of conceptual relationships. According to Mustafa Cakir (2008), the crucial difference between the above two categories of concepts is the existence and absence of a system. Spontaneous concepts do not form a coherent system while non-spontaneous concepts do. The above shows common grounds exist for the learning theories related to conceptual change.

3.4 Differences between Learning Theories

Piaget's learning theory is stage dependent and there are four distinct stages of cognitive development from birth to adulthood. Salvin (1988) asserts that children learn concepts at increasing levels of abstraction depending on their level of maturity. The learning theory of Ausubel (1978) emphasizes prior knowledge as the major determinant of learning and it is not stage dependent. And the learning theory of Vygotsky (1978) focuses on importance of language in mediating thought. Piaget gave little attention to language and he took language as a means of expressing thoughts that had already developed (Gredler, 1997). For Vygotsky (1978) language or words are the means through which thought can be formed. According to How(1993), "it is important to go beyond direct experience in teaching scientific concepts and to mediate experience with words; experience alone is not enough since the experience is an isolated observation unless it is put into words and understood in a larger context". Ausubel (1978) used his "Reception Learning Instructional model (RLIM)" and "Advance Organizers' Model (AOM)" in the "top-down" approach to instruction. Piaget (1985) used a "bottom-up" approach to instruction and for him the learning is in which the learner acquires pieces of the larger picture before gaining access to an overall view. Bruner's approach is that of extending the ZPD of Vygotsky using an instructional method called scaffolding (Gredler, 1997: 103). Scaffolding is a method in which a tutor(adult or capable peer) assists the learner build an extension from an existing schema into new cognitive territory through a series of small steps of which the learner cannot do it alone or capable of doing it alone. The tutor and the learner should develop a kind of mutual understanding of each other's intentions and ideas as the extension is

constructed. In this process, the tutor should eventually withdraw his/her support, leaving the learner under his/her own full command/ control of the newly constructed extension and thereby developing the ultimate, somehow, independent learner. The goal of quality education is the creation of critical and reflective thinkers and socio-cultural collaboration can only be fulfilled in this way. Most of the above theories fall under cognitivism and constructivism. Piaget (1978) and Ausubel (1978) were cognitive psychologists and are very close to radical constructivists such as von Glasersfeld (1995) whereas Vygotsky (1978) was a social constructivist. Many researchers nowadays believe that constructivism is the right kind of epistemology and learning theory on which to base our science instruction (Martin, 2003).

3.5 The Two Major Variants of Constructivist Learning Theory: Radical Constructivism and Social Constructivism

According to Naussbaum and Novick (1982:184), "the conclusions ... of leading theories in cognitive psychology seem, therefore, to be mutually supportive." Yeany (1991:3) critically suggested that the theory "seems so elastic that, instead of demanding adherence, it simply accommodates many perspectives." According to constructivist epistemology, science cannot transcend the domain of experience. Scientific theories are taken as models which help and order that domain of knowledge. Models raise questions in semantics--what is the representational function that models perform? , In ontology--what kinds of things are models?, In epistemology--how do we learn with models?, and in philosophy of science--how do models relate to theory? Models can be replaced by others as experiential field expands. Einstein (1955:1) asserted that "the object of all science, whether natural science or psychology, is to coordinate our experience and to bring them into a logical order." The task of scientists is to create conceptual structures and fit their experience with it. Scientists invent theoretical models and test their viability in repeated and controlled experiences which they call "experiments".

3.5.1 The Radical Constructivist View of Learning

Von Glasersfeld (1995:2-3) set forth the following principles regarding the description of knowledge and the development, nature, function and purpose of knowledge.

The first principle is that how knowledge is, and is not, constructed. Knowledge is something actively constructed by a thinking person from within. The second principle is about the importance of social interaction in the construction of knowledge. Social interaction among learners is central to the individual or personal construction of knowledge. The third principle takes note of the adaptive and functional character of cognition. Cognition and the knowledge it produces are higher forms of adaptation in the biological context. The fourth principle describes the purpose of cognition, especially what it is and what it is not. The purpose of cognition is to

organize learners' experiential world and it is not the discovery of an objective ontological reality (my emphasis).

According to von Glasersfeld (1995: 2-3), a leading radical constructivist, knower cannot objectively test the accuracy of correspondence between human knowledge and the external world, as the process of human knowing itself makes objectivity impossible. The purpose of cognition is to organize his/her experiential world and it is not the discovery of an objective ontological reality. Constructivism is more of an epistemology (philosophy) not a strategy for teaching. Ontologically, mental representations have "real" ontological status just as the "world-out-there". Epistemologically, knowledge is individually constructed and inside the person's mind, not "out-there". The nature of human interaction as a shared or "negotiated" meanings are better thought of cooperative than authoritative or manipulative in nature. The nature of science can be taken as a meaning making activity which filters the biases accompanying any human activity. Thus constructivism not only addresses knowledge construction at content level, but also addresses issues of metacognition as stated above.

Einstein asserted ideas which have relevance to radical constructivism:

Physical concepts are free creations of the human mind and are not, however it may seem, uniquely determined by the external world. In our endeavor to understand reality we are somewhat like a man trying to understand the mechanism of a closed watch. He sees the face and the moving hands, even hears it's ticking, but he has no way of opening the case. If he is ingenious he may form some picture of a mechanism which could be responsible for all the things he observes, but he may never be quite sure his picture is the only one which could explain his observations. He will never be able to compare his picture with the real mechanism and he cannot even imagine the possibility or the meaning of such a comparison (Einstein and Infeld, 1967:31).

Einstein's idea forms the core idea of constructivist epistemology. The scientific method and the results obtained thereof are 'objective'. Philosophers ascribed the term 'objective' to 'existence' which posits entities supposed to be independent of any one's experience. Einstein's idea suggests that our individual abstraction from experience is different from each other. Thus, it would be preferable or more accurate if in all cases we consider 'intersubjectivity' rather than 'objectivity'. The words 'objective' and 'objectivity' are deliberately intended, according to philosophers, to imply direct knowledge of things as they are 'in themselves' or knowledge of items as they might be prior to being experienced. According to constructivists' contention, 'objectivity' is the delusion that observations could be made without an observer (von Glasersfeld, 1995). For the purpose of elaboration, Humboldt (1907:581 cited in von Glasersfeld, 2001) expressed how our mind mirrors reality:

1. *The essence of thinking consists in reflecting, i.e., in distinguishing what thinks from what is being thought.*
2. *In order to reflect, the mind must stand still for a moment in its progressive activity, must grasp as a unit what was just presented, and thus posit it as object against itself.*
3. *The mind then compares the units, of which several can be created in that way, and separates and connects them according to its needs (my emphasis).*

In von Glasersfeld (2001), the expression 'the progressive activity', was interpreted as the mind's segmentation and coordination of the flow of the raw experiential material that Emanuel Kant (1800:144 cited in von Glasersfeld, 2001) called 'the manifold'.

the sensory perceptions (conscious empirical presentations) can only be called internal appearances. Not until understanding is added (and makes order in the manifold) does empirical knowledge, i.e., experience, arise from it." (Kant's emphasis)

Earlier Kant (1787: xvi cited in von Glasersfeld, 2001) formulated the same in a less emphatic tone "that reason can comprehend only what she herself has brought forth according to her design". Piaget's theory of cognitive development was created by disagreeing with Kant's notion of 'a priori' or that is not experienced but thought. Piaget (1937) replaced it with a developmental model of the children's construction of space, time, permanent objects, and causal relations among them. The creation of these fundamental concepts begins with the construction of objects that show up recurrently in the children's experience. For Piaget, the purpose of cognition is the organism's adaptation to the world as it is experienced. Adaptation is not only the main goal of cognitive activity but also the elimination of all that is not adapted.

According to Stephen Hawking (1988:10), "a physical theory is always provisional, in the sense that it is only a hypothesis: you can never prove it." Both Hawking and Einstein expressed a deterministic view of the universe in that, taken for granted, human reason can recognize and understand an observer-independent structure of the universe and at least in principle, physics can devise theories which describe the universe as it exists. Einstein took that position when he negated the quantum uncertainty and promoted his Newtonian deterministic view of science. As any other rational knowledge, scientific theories are derived from human experience and formulated in terms of human concepts and reflection of the experiential interface. *Therefore, there is no clear cut boundary between what is rationally thought and what is experienced (my emphasis).*

Constructivism denies that we can rationally know reality beyond experience or empirical knowledge is the only kind of knowledge from which we perceive reality. In school science, students personally construct meaning from facts, concepts, relationships, principles, and generalizations, which are referred to as conceptual structure or framework. Learners learn by actively constructing meaning from their experiences. Constructivism is a theory of knowing (epistemology), not of being and model of construction of knowledge could be designed without making ontological claims about what is known is generally difficult to accept. Thus for radical constructivists, students can personally construct knowledge based on the meaning making activity out of their experience.

3.5.2 The Social Constructivist View of Learning

According to Driver and associates (1994), Piaget's theory and theories based on his ideas have been characterized as personal constructivist theories as they focus on the individual's personal construction of meaning through interaction with the physical environment. The orthodox conceptual change model of Posner and associates (1982) is a personal constructivist model. The orthodox model provides children with physical experiences such as demonstrations or experiments they can perform that can make them dissatisfied with their originally held/alternative conceptions. Driver and associates (1994) noted that the task of the teacher is to provide the physical experience and finally give reflection. Traditional instruction texts will not help students construct new knowledge. However, texts and demonstrations are combined by science education researchers to effect conceptual change.

Based on the ideas of Vygotsky (1978), social constructivism maintains that all higher mental functions originate in social interaction. Meanings can be externally and socially constructed before learners make them personal and internalize them. Cognitive processing on both the external/social and individual/internal planes is always mediated by tools and science, most importantly language. Vygotsky used the phrase '*inner speech*' to label processes that others would refer to as cognition or information processing (Wretsch & Toma, 1995). According to Vygotsky (1978: 86), learning takes place first on the social plane and postulated that children are able to engage in problem-solving tasks "under adult guidance or in collaboration with more capable peers" which they cannot do it independently. Adults consciously control these tasks in the process of scaffolding the child. Interaction or dialogue with more knowledgeable and skilled members of the community allows the child learn social languages. This social or community languages expanded Vygotsky's ideas to provide more emphasis on the socio-cultural setting in which learning takes place (Baktin's, 1986). The community can be teachers and students in the classroom. The social discourse of a community allows individuals to construct personal knowledge. The social constructivist instructional strategies which involve conceptual changes include-use of personal experiences in instruction, nature of language used and historical, cultural, institutional settings, and

nature of group interactions. Constructivist epistemology is based originally on monist philosophy in which the human mind and the external world are functionally unified but later on as sects such as radical constructivism and social constructivism begin to appear, constructivism fell back into Cartesian separation of mind and the external world. Philips (1995), "praised constructivism for its emphasis on learners' active participation and the heightened recognition given to the social nature of learning".

Constructivism is criticized for its tendency towards epistemological relativism, more specifically, individual and social/community relativism. Vygotsky (1962) criticized the behaviorists as "being too narrow, specialized, isolated and intrapersonal in position". And information-processing approaches are criticized as "being overly reductionist in its analogy of computer and mind" (Mayer, 1996). Both failed to address active nature of learning and the impact of the social interactive contexts in school settings. "Their positivist view of the universe proved inadequate to capture the active and social characteristics of learners" (Philips, 1995). Behaviorism and information-processing took the mechanistic positivist accounts of students as recipients of knowledge. Human subjectivity, which was excluded by 'objectivist' behaviorists and information-processing accounts, returned to constructivism in which the relation between the objective (world) and subjective (mind) is emphasized.

Personal constructivism stemmed largely from Piaget's (1978) work, with followers such as Bruner (1960), Ausubel (1978), and von Glasersfeld (1995). Theories affiliated with this line of thinking focus on the intrapersonal process of individual knowledge construction. Knowledge is not a self-sufficient entity; that knowledge is not directly transmittable from person to person, but rather is individually and idiosyncratically constructed or discovered. The social/realist constructivism, however, is due to the work of Vygotsky (1978) with followers such as Kuhn (1962), Greeno (1989), Lave (1988), Simon (1989a) and Brown (1987). In personal constructivism, social environment and social interaction work merely for individual cognitive processes. The learning community encultures learners based on existing understanding and immediate learning environment. Therefore, learning can be taken as situated or situation specific and context-bound activity (Eiggen & Kauchak, 1999; McInerney & McInerney, 2002; Woolfolk, 2001). Personal constructivism asserts that a mind-dependent existence and all persons cannot have a uniform cognition. Social constructivism demands a cross-community transfer of knowledge. The two perspectives: radical and social constructivism show relativity of knowledge where no absolute single truth exists.

The dualist thought implicit in constructivist epistemology polarized Piaget (1978) and Vygotsky (1978) along the individual and the social. Behaviorism could not address the relationship between mind and body or external world; *constructivism overcame this difficulty of mind-body/ mind-external world dualism by postulating the interactivity of human mind and the world (my emphasis)*. Hualiu and Matthews (2005) assert that dualism is the true paradigmatic framework behind so much of constructivism. According to them a paradigm is a general hypothesis/orientation about 'the truth', but not a complete truth. But Liu (1989) took a paradigm shift / 'gestalt shift' as "something that does not involve the complete and total change in more detailed and particular problem solving methods". Therefore, paradigm or 'gestalt' shift does not actually entail epistemological relativity as argued by Kuhn. Kuhn was a social community relativist. Some educators believe that subjectivity should not be superior to objectivity because the concrete laws of problem solving must be established on the basis of empirical evidence.

Lave and Wenger (1991:47) in their situated learning theory contend that Vygotsky's (1978) internalization, generalization, and scientific concepts contain only "a small 'aura' of socialness that provides input for the process of internalization, viewed as individualistic acquisition of the cultural given." Role of social collectivity in individual learning and development is the focal point in Vygotsky's (1978) theory. It: (a) emphasizes the role of the social and the collective, but ignores the role of the individual (Resnick, 1996); (b) fails to address how the external is bridged across to the internal mind (Fox,2001 & Cobb,1996); and (c) implies a " blinkered social consensualism"(Fox,2001), and therefore epistemologically social relativist. Radical constructivism considers the individual and the social as basically mutually exclusive. For Vygotsky(1978), the relations between the social and the individual in the process of social and individual development are that of dialectical interaction and functional unification. We cannot conceive mind as something independent of the socio-cultural group. In my SCSMCC as integrated model I took the monist functional unity of mind and body/external world as a right kind of epistemology in which the individual and social are not mutually exclusive. The only difference with Vygotsky (1978) is that asymmetry and primacy of the social over the individual is rejected. Similar asymmetry and primacy of the individual over the social by radical constructivists is rejected.

Cobb (1996:339) summarized the process of individual development as the individual mastery and development must be based on history and culture and the individual should stand above the social collective because of the ability of the mind to generate personal understandings. Vygotsky (1978)

"argued that knowing is relative to the situations in which knowers find themselves". In contrast, Wretsch (1985:60) asserted that:

Vygotsky's statement that any function in the child's cultural development appears twice, on two planes. First, it appears on the social plane, and then on the psychological/individual plane. It appears between people as an interpsychological category, and then within the child as an intrapsychological category, education not only content with children's enculturation, but also promote individual consciousness as a consequence of enculturation.

According to Eggen and Kauchak (1999:285), the Vygotsky's (1978) stand contrasts with situated learning theory, which " suggests that learning is bound to the specific concrete situation in which it occurs, and transfer is difficult, if not impossible." The Social Learning Theory (SLT) of Bandura (1977) underpins that individual as non-initiative beings receive one sided external forces from the social. The collective is always larger than the total sum of separate individuals. The social is an external world to the individual which is given shape historically by collective participation and collaboration. Fox (2001:21) questioned how language can become "the material out of which most constructivists seem to build knowledge" and he also argued:

Another variant of this extreme socialization theory is to argue that all knowledge is based on language and on linguistic representation, or perhaps on semiotic systems more generally. Human minds are said to be "shaped" by language, although it is not clear why this one form of experience is held to exclude others (v.z., perceptual experience, practical trial and error and non verbal emotion). If held literally, this view denies any knowledge to infants in their pre – linguistic phase (all of Piaget's sensory motor intelligence) and tends to imply that animals cannot know anything. It also ignores all the implicit knowledge we have of the world which we have never put into words (Fox, 2001:29-30).

In Robbins (2001), Vygotsky's (1978) focus on psycholinguistic studies is on language use and word meaning. "His linguistic study was like today's semantics, pragmatics and study of discourse. Vygotsky stresses carefully that one cannot reduce beyond word meaning without great loss in understanding." Robbins (2001:47) asserts that the socio-psychological nature of word meaning and its function in intellectual development is that:

The word does not relate to a single object, but to an entire group or class of objects. Therefore, every word is a concealed generalization. From a psychological perspective, word meaning is first and foremost a generalization. It is not difficult to see that generalization is a verbal act of thought; its reflection of reality differs radically from that of immediate sensation or perception....At the same time, however, meaning is an inseparable part of the word; it belongs

not only to the domain of thought but to the domain of speech. It is obvious, then, that our method must be that of semantic analysis.

Semantics, as an interaction between individuals and society, is the result of a continuum of time and historical and cultural development. The transition from immediate sensation to thinking is what distinguishes humans from animals. For Vygotsky (1978): (1) consciousness is defined as an individual's general perceptual orientation. Mastery of language, resulting in the development of conceptual system, and consciousness are all but different aspects of the same process which is that of intellectualization; (2) in the development of consciousness, the sequence is from the social to the individual. Regarding the second point, I contend that there is no primacy of either the individual or the social at the initial point of learning but after that the individual and the social alternate cyclically and continue spirally in the life time of an individual.

According to Vygotsky (1978:190), consciousness is the ability to perceive meaningfully. He suggests that to perceive something from a meaningfully different perspective enables one to move from spontaneous concepts to more generalized concepts. He explained the genesis of consciousness in the child, and the development of consciousness is a process of functional unity of mental operations as:

[T] he child's mental development consists not so much in the development or maturation of separate functions as in changes in the connections and relationships among the functions. Indeed, the development of each mental function depends on these changes in inter functional relationships. Consciousness develops as a whole. With each new stage in its development, its internal structure – the system of connection among its parts – changes. Development is not a sum of the changes occurring in each of the separate functions. Rather, the fate of each functional part of consciousness depends on changes in the whole. ... These inter functional connections and relationships are neither constant nor inessential. They cannot be placed outside the analytic frame within which psychological investigation are carried out. Change in this inter functional connections – change in the functional structure of consciousness – is the main and central content of the entire process of mental development. ... If we fail to resolve this problem, we will not be able to understand the changes we observe in the isolated functions (Vygotsky, 1978:187-188)

Vygotsky (1978:190) differentiated consciousness, the ability to perceive meaningfully, from conscious awareness and defined conscious awareness as “an act of consciousness whose object is the activity of conscious itself.” He defined consciousness as “the ability to produce meaningful generalization and connecting relationships between objects and concepts and conscious awareness involves the ability to interconnect processes of mental activities”. When the individual recognizes his/her conceptual system,

s/he acquires potentials of perceiving new connections and of new possibilities of action. Consciousness refers to the general organization of one's conceptual system, which orientates one's perception and sense-making. Robbins (2001: 21-22) has the following to say about the social origin of consciousness:

It is important to remember that the social precedes the individual in Vygotsky's understanding of consciousness, and that it is created and expanded through interaction with the world, and "Like Marx, Vygotsky... argued that 'the social dimension of consciousness is primary in time and fact. The individual dimension of consciousness is derivative and secondary based on the social'" (Wertsch, 1983:22). Vygotsky stated that "this also means that consciousness cannot focus on itself, that it is a secondary and derivative activity" (Vygotsky, 1978:27).

"The fact that the individual personality is shaped by the social environment points to the fact that the individual draws from society the resource for growth" (Hualiu & Matthews, 2005). Therefore, the change and growth of the society and individuals are closely interconnected. Language is the mediator of all higher mental functions. Language is the product of history and the internalization of linguistic generalizations, therefore, makes the individual's mental functioning the product of human history as well (Bruner, 1978). Vygotsky (1978) argues that history and culture lead to internalization, and to personalized generalization, and the internalization developed in such a manner will go, by the individual, beyond history and culture. Robbins (2001) asserts that Vygotsky (1978) based his conceptualization of individual development on the transcendental and heuristic nature of dialectics:

Much of Vygotsky's works are based on dialectical principles and it is important to realize that the dialectic is not a scientific inductive approach used to arrive at a finished product (i.e., ergon). Indeed Engels stated that there are no hard and fast rules in dialectics (cf, Engels, 1925, p. 153). The dialectic contains no exact element where proof can be obtained and it possesses only a small element of deduction (Robbins, 2001: 65-66).

Regarding the individual, Robbins (2001) has this to say: "[W]ith in this system of dialectics the individual does not experience social relations as something completely external, and although the individual as a particular derives consciousness, that aspect remains a generalization or idealization of experience" (Robbins, 2001:67). According to Vygotsky (1978), there is a functional relationship between the individual and the social and they exist in interdependency and form a dialectic organic whole. Vygotsky (1978) was very sound in his functional unity and interdependence between the individual and the society except his asymmetry of the two and I believe that this will guide my research. I simply do not agree with the asymmetric nature of his theories. Vygotsky's (1978) educational

philosophy regarding the relationship and interaction of the mind and the external world is reflected in the following three aspects: (a) the social collectivity is a qualitatively different entity from the total sum of isolated individuals; (b) language functions both as indicator of the objective reality and as the mental generalizations of activities; and (c) that consciousness conceptualized as human rationality and the endless potential of the development of rationally rooted in the ceaseless dialectics of mind and world.

3.6 The Origin of Learning as Conceptual Change in Science Education

Studies of pre-instructional conceptions on various science content domains have shown that students come to science classrooms with some preconceived knowledge or belief about the concepts taught in that domain. The idea of conceptual change has its roots in Kuhn's conceptions of theory change (Kuhn, 1962: *The Structure of Scientific revolutions*). Conceptual change has also its base on Piaget's (1978) cognitive psychology of assimilation, accommodation and equilibration. Kuhn (1962) challenged the conventional view that scientific knowledge progresses in a cumulative manner by piling on to the stock of available theories and concepts. He tried to show that the development of science often involves revolutionary changes in which a paradigm shift occurs or in which one theory or paradigm is replaced by a radically different one. For example, acceptance of quantum mechanics required the rejection of classical mechanics in some domains of physics. The radical changes also involved the redefinition of concepts used in the theories. For example, in Copernican theory the concept of 'planet' shifted to include the earth and exclude the sun and the moon. Kuhn gave a clear distinction between normal science, in which a dominant paradigm is taken for granted, and revolutionary science, in which the dominant paradigm is replaced by a radically new one. Puzzle solving is the major and traditional activity in normal science. Puzzles are problems which are delimited and constrained by the dominant way of thinking. The accumulation of anomalies which cannot be solved by normal science produces a crisis which urges scientists to formulate new theories. The replacement of the old paradigm by the new paradigm necessitates a scientific revolution and the new theory becomes acceptable. According to Kuhn (1962), the old and new theories are incommensurable with each other. And the main source of incommensurability is the use of different concepts by different paradigms. For example, Einsteinian mass is convertible to energy, but Newtonian mass is conserved. Radical conceptual change is the major aspect of scientific revolutions.

Thagard (1992) asserted that scientific revolutions mostly involve the introduction of new concepts and Kuhn overestimated the conceptual differences between theories, and hence conceptual change, on the basis of explanatory power, can rationally choose one theory in preference to another. However, Thagard(1992) accepted Kuhn's basic contention that new theories often have different conceptual systems from the ones they replace. Thagard (1992) asserted that new concepts are rarely derived directly from experience, but derived from previously existing concepts. He had also shown that analogy is

another mechanism of forming new concepts by adapting and transforming previous concepts. In support of this argument, Nersessian(1992) asserted that, for example, Maxwell developed laws of electromagnetism based on mechanical wave's analogies. This shows that, combination and analogy mechanisms are used in the development of a new conceptual system. Explanatory coherence is the major cognitive mechanism for large scale conceptual change as it is more coherent with other beliefs and provides a better power of explanation of the evidence (Thagard, 1992). For him, except introduction of new concepts in existing conceptual schemes and theories, substantial revisions of existing conceptual systems on a large scale may not be needed for conceptual change to occur. The way concepts develop in children is like theory change in science which requires substantial revisions of existing conceptual schemes. Like scientists, children have theory-like conceptual structures but not just cumulative additions to them, and learning involves radical changes of such structures. Shifts in students' understanding may be like theory change in science by scientists. Conceptual development is not just a matter of accumulating new concepts but also a matter of changes in concepts and conceptual systems. The process of discovery is similar to children's inquiry. However, children's knowledge is much more fragmented and internally inconsistent than that of scientists. While scientists use hypothesis to guide unifying explanations of empirical evidence, it is not yet well-established that similar explanatory hypothesis is used by children. But a common set of cognitive processes exist between them.

Novak (1996) regards concepts as packages of meaning; they capture regularities, patterns, or relationships among objects, events, and other concepts. Concepts are not formed due to interplay of associations but an intellectual operation for which language is a guide and in which mental functions such as memory, attention and inference participate. Concept acquisition is a long process and there is no such thing as the final and complete acquisition of a concept (Pines, 1985). The spiral in my SCSMCC depicts this fact and the quest for knowledge is eternal. Concepts get differentiated in the mind of a person (Thagard, 1992). Understanding and communication occurs because of overlap between persons' conceptual-cognitive structures.

According to Carey (1992) and others, there are two types of conceptual change: (a) weak knowledge restructuring, assimilation or conceptual capture and (b) Strong, radical restructuring, accommodation or conceptual change. **Conceptual change has become the term denoting learning science from constructivist perspectives (Duit, 1999).** Epistemological positions combining radical and social constructivist approaches appear to be more promising than adherence to single theory views, and the synergy of paying equal attention to the individual and social aspects of learning are powerful tendencies in the teaching and learning of science(Duit & Treagust,1998)(my emphasis).

3.7 The Various Conceptual Change Theories in Science Education

The two prominent competing theoretical perspectives regarding knowledge structure coherence are: (1) knowledge-as-theory perspectives and, (2) knowledge-as-elements perspectives. Proponents of knowledge as theory perspectives argue that student's knowledge can be most accurately represented as a coherent unified framework of theory-like character (Carey, 1999; Chi, 2005; Ioannides & Vosniadou, 2002; Wellman & Gelman, 1992). And proponents of knowledge-as-elements perspectives considered knowledge as ecology of quasi-independent elements (Clark, 2006; diSessa et al., 1999; Linn et al., 2004). These two categories of perspectives implicate radically different routes for curricular design that assist learners restructure their understanding of science.

3.7.1 Knowledge-As-Theory Perspectives

History and philosophy of science and Piagetian learning theory influenced the creation of knowledge-as-theory perspectives. Vosniadou (1994) and Vosniadou & Brewer (1992) explained conceptual change in terms of framework theories and mental models. Chi (1992) focused on ontological shifts. Posner and associates (1982) forwarded a conceptual change theory based on Kuhn's ideas of normal science and paradigm shift, and based on Piaget's notion of accommodation. If existing schema can allow a student to solve problems or even cannot solve problems, the learner can only make moderate changes to his conceptions known as "conceptual capture" (Hewson, 1981) or "weak restructuring" (Carey, 1985). This is also what Piaget called assimilation. According to Posner and associates (1982) model of conceptual change, learners must be dissatisfied with their initial conception in order to discard it and change their conceptions to the scientific one. Hewson (1981) called this radical change as "conceptual exchange" or Carey (1985) called it "radical restructuring".

For Posner and associates (1982), in addition to dissatisfaction, the scientific conception must be intelligible (conception must be clear enough), plausible (conception must be plausibly true), and fruitful (productive in solving problems). These cognitive conditions must be satisfied for successful conceptual change to happen. The aim is to create cognitive conflict so that the learner feels dissatisfied with his existing conception. These authors embedded their description of conceptual change in a conceptual ecology perspective. Conceptions and epistemological beliefs determine the conceptual ecology of the learner. Misconceptions and prior conceptions are highly resistant to change. Since concepts are related in a web-like structure, changes in one concept necessitate changes in other related concepts. Strike and Posner (1992:155-156), showed how the components of an individual's conceptual ecology interact and develop and how it interacts with experience. Understanding such interactions helps in understanding the basic problem of cognitive development. Carey (1985; 1991) found out that adult's and children's concepts, which are theory like, are both coherent but incommensurable with each other. For her the three

processes of conceptual change are: replacement, differentiation, and coalescence. In replacement two different concepts exchange place; in differentiation the original concept splits into a number of concepts, for example, "mass" differentiates into "inertial" mass and "gravitational" mass; and the reverse process of differentiation is true for coalescence.

Unlike Kuhn's revolutionary change which demands instant change, Carey's (1999) research shows that gradual/slow changes are more fruitful. She proposed the idea of "domain specific restructurings" and rejected Piaget's "global restructuring" in conceptual change. The restructuring occurs as a result of the learner's increased knowledge of the domain, social interactions, and variety of disequilibrating influences. For her, beliefs are the relational pieces that relate concepts. The two primary components of intuitive knowledge are concepts and beliefs. And conceptual knowledge is acquired as a result of gradual process at specific concept level. Formal instruction restructures naïve knowledge constructed through everyday experiences. Vosniadou & Ioannides (1998) came up with spontaneous and instruction-based changes using their mental model theory. Spontaneous changes occur without specific instruction. Formal instruction can result in gradual/evolutionary changes in children's mental models. This is similar to Carey's (1999) idea. Children's science lack both ontological and epistemological commitments. Vosniadou (1994) came up with learner's framework theories (mixture of their initial model and scientific model) which constrain their learning of scientific concepts. Chi (1992) showed that conceptual change requires an ontological shift, which is similar to framework theory perspective. For him "conceptual change is difficult for two reasons: (a) the learner assigns a concept to a different ontological category from the one accepted by the scientific community; or (b) the learner lacks knowledge of an appropriate category to which the concept could be assigned". According to him, this is an evolutionary process. The process is gradual because the student needs to revise and restructure an entire mesh of beliefs and presuppositions. However, Vosniadou & Ioannidis (1998) suggested that changing ontological categories is only one aspect in the process of changing theories.

Children not only lack ontological and epistemological commitments but also lack hypothesis since their concepts are developed unconsciously. Indeed, their alternative conceptions constrain the learning of scientific concepts. Some knowledge-as-theory perspective proponents took Kuhn's idea of revolutionary changes or Piaget's notion of assimilation and accommodation, while others used the idea of incommensurability between novices and scientists conceptualizations and took an evolutionary stance. Chi (1992) and Vosniadou (1994) took ontological shifts and evolution of mental models which is again a gradual process. What is common about theories in this category is that learners hold a small number of

well-developed coherent naïve theories and that these theories have explanatory power to make consistent predictions and explanations across significant domains.

3.7.2 Knowledge-As-Elements Perspectives

An opposing perspective that characterizes students' understanding in terms of collections of multiple quasi-independent elements is advanced by (Brown, 1995; Clark, 2006; diSessa, 1988, 1993; Hunt and Minstrell, 1994; Linn et al., 2004). Anderson (1993) and Thagard (1992) provide relatively mechanical/mathematical examples of this perspective. Clark (2006), diSessa and associates (2004), maintain more of organic perspectives which focus on collection of perspectives including, but not limited to, phenomenological perspectives (P-prims), facts, facets, narratives, concepts, and mental models at various stages of development and sophistication. diSessa focuses more on the nature of the elements, Clark focuses on longitudinal processes of change; Minstrell focuses on facets students use in the classroom, and Linn on the process through which learners recognize, revise, and relate these elements. Therefore, learning occurs by way of restructuring and reorganizing these ideas. diSessa's perspective is the most dominant from among knowledge-as-elements perspectives. diSessa (1993) proposed that the knowledge structures of novices consist primarily of unstructured collections of many simple elements that he calls p-prims (phenomenological primitives). P-prims are not highly organized theories but are developed through experience, observations, abstraction of phenomena, and through interactions with the physical world via our senses. Examples of P-prim are: heat as energy in transition, temperature as average kinetic energy of molecules, force as a mover, and force as a deformer. Each p-prims are loosely connected into larger conceptual networks. diSessa describes cuing priority, reliability priority, and structured priorities to propose how these p-prims are recognized and activated according to context. diSessa's argument is supported by empirical evidence. Southerland and associates (2001) found out that p-prims have more explanatory power than conceptual framework theory in studying students' biological knowledge structure. Clark (2006) conducted a longitudinal study in thermodynamics and found out that students' conceptual understanding can be explained more by using p-prims than knowledge-as-theory perspectives.

Novices spontaneously connect and activate fragmented and incoherent knowledge pieces according to the relevance of the situation. In the process of conceptual change, the knowledge elements and interactions between them are revised and refined through addition, elimination, and reorganization to strengthen the conceptual network. In this perspective, conceptual change is viewed as a piecemeal evolutionary process rather than as a process of broad theory- change.

According to Özdemir and Clark (2007), the two perspectives agree on the following three points:

- *Learner acquire knowledge from their daily experiences*
- *Learners' naïve knowledge influences their formal learning*
- *Much naïve knowledge is highly resistant to change. Thus, conceptual change is a time consuming and evolutionary process.*

Table 3. 1: Disagreements of the two perspectives on knowledge generation

Knowledge-As-Theory Perspectives	Knowledge-As-Elements Perspectives
1. Naïve knowledge is highly organized in theory, schema, or frameworks.	1. Naïve knowledge is a collection of quasi-independent knowledge elements.
2. Naïve knowledge in a coherent form has explanatory power to consistently interpret the situations across broad domains.	2. Consistent application over time for individual contexts, and systematicities will be present, but with high contextual sensitivity.
3. More focus on revolutionary replacement of naïve knowledge in a manner similar to Kuhn's perspectives on paradigms in science. Significant coherence between ideas at any given point in time.	3. More focus on conceptual change involving evolutionary revision, refinement, and organization. Multiple conflicting ideas may co-exist simultaneously at any given point in time.
4. Explanations involve the creation of mental models constrained through the overarching/main framework theories or ontological categories.	4. Explanations involve the p-prims and other elements within the learner's conceptual ecology that are most strongly cued by the context.

(Adapted from: Özdemir,G. and Clark,B.(2007))

3.7.3 Empirical Evidence For and Against the Two Perspectives

Recent findings on Knowledge Structure Coherence (KSC) support knowledge-as-elements perspectives.

Ioannides and Vosniadou (2002) and diSessa and associates (2004) conducted series of studies and replication studies on Knowledge-as-elements and knowledge-as-theory perspectives. Ioannides and Vosniadou (2002) investigated the meaning of force and its development using framework theory among 105 children across 4-age levels. 88.6% of the respondents' answers fell into seven categories of internally consistent interpretations of force. The seven categories of force they studied include: (a) internal force, (b) internal force affected by movement, (c) internal and acquired force, (d) acquired force, (e) acquired force and force of push/pull, (f) force of push/pull and (g) gravitational and other forces. They concluded that students' interpretations of force were uniform and internally consistent. diSessa and associates(2004) conducted an extension of the Ioannides and Vosniadou(2002) study and its quasi-replication. They found that the coherence claim could not explain students' meaning of force. Students' answers were inconsistent in differing situations, even when asked in the replicated study. The results also

supported several alternative explanations in which the learner's understanding of force is context-independent or invariant under the change of contexts. diSessa's (1993) children's naïve knowledge consists of fragmented and unstructured small pieces that are unconsciously activated in certain circumstances was supported. This is conflicting finding, of coherence versus fragmentation; with the above authors suggest that students' interpretation of force supports knowledge-as-elements perspective over all. The results have shown contextual sensitivity. Wagner's (2006) **case study analysis** has shown that students' conceptual understanding is often highly situation or context dependent/sensitive. Clark's (2006) longitudinal study in thermodynamics showed that "students' explanations *evidenced* multiple contradictory ideas, disruptive experientially supported ideas, difficulties productively connecting normative ideas, and the active pursuit of ideosyncratic explanations". There was no consensus on Knowledge Structure Coherence (KSC) and the mechanism of conceptual change.

We need to determine whether students' intuitive knowledge involves many quasi-independent elements or a network of theories. This affects our understanding of instructional strategies, conceptual change process, and curriculum design. In Posner and associates' (1982) model creating cognitive/conceptual conflict is the main strategy of instruction for conceptual change. If evidence supports that knowledge of the learner is elemental, instruction should focus on how those elements are activated in appropriate contexts. A curriculum design which exposes students with the same phenomena in different contexts is important. Knowledge-as-elements perspective supports socio-culturalism or situated cognition and theories related to them. Such curriculum should focus on refinement process such as addition, modification, elimination, and organization of knowledge elements in the course of time. Constructivists believe in progressive knowledge building. It is important to reprioritize and reorganize the elements and connect them with their conceptual framework which leads the students to construction of a theory that is applicable to many situations/contexts. Constructivism considers students' existing ideas as a primary source of learning. Constructivism characterizes the process of learning as the gradual recrafting of existing knowledge that is eventually successful. However, many misconceptions research results/assertions are inconsistent with constructivism. According to Smith and associates (1994), it is not easy to see "how misconceptions: (a) interfere with learning, (b) must be replaced, and (c) resist instruction and play a role as useful prior knowledge in students' learning". Refer to the 'initial personal thinking' in SCSMCC as integrated model which gives time for the learner to reorganize his existing knowledge about the concept presented, before moving on to the next stage of instruction.

P-prims describe the events in the physical world in terms of intuitive conceptualization (diSessa, 1993). P-prims must be cued in several relevant and suitable contexts in which students construct a complex and

stable formal knowledge. Particularly in complex and rich domains such as thermodynamics and mechanics, elements perspective use instructional strategies in which concepts are restructured, edited, and organized rather than discrete change of concepts. According to Ainsworth (1999) these can be achieved by using multiple representation of concepts and consider specific aspects of the phenomenon across multiple contexts. Wiser and Amin (2001) suggested that conceptual change involves both revolutionary and evolutionary aspects. DiSessa and colleagues are currently engaged in systematicities and connections between ideas rather than in quasi-independence of the different elements. Özdemir and Clark (2007) suggested that the above two perspectives are converging to account for coherence, systematicity, and transition. **Times of transition in students understanding is best described using elements perspective and theory perspective finally acknowledged that conceptual change is evolutionary and provide few tools for mechanisms of transition (my emphasis).** The spiral in SCSMCC depicts this fact. Times of transition must be shown by modeling and explaining how it occurs and may be extended to the whole period of schooling and adulthood. Clark (2006) conducted a longitudinal study in thermodynamics from grade 8 up to grade 12 and has shown ongoing transition across the school years. Transitional and coherent phases are well-accounted for by elements perspective than theory perspective which believes in radical/revolutionary changes.

3.8 The Context of the Research and Lack of Constructivist Conceptual Change Strategies in Ethiopian Secondary School Science Curriculum

At the time when I started developing my research proposal, the curriculum in Ethiopian secondary schools was based on the traditional plasma TV teaching. Both face-to-face and the distance TV teaching were using traditional lecture and rarely demonstrations. The ETP (1994) advocated the use of learner centered methods in teaching secondary science but in practice the plasma TV teaching by its very nature cannot be a learner-centered method as it used lecture supported by demonstrations. There was no chance for the students to participate as the methods are traditional teacher-centered methods. The school teacher was used as an aid to the plasma TV teaching. In the mean time after my defense of the PhD proposal, I changed my mind to work on development of conceptual change model and implement it in our context. Based on literature review I came up with my own conceptual change model and got the approval of my advisor to implement it in my quasi-experimental design. However, in September of 2010 the Ministry of Education released a new so-called constructivist curriculum which I had to analyze using documentary evaluation of teacher guides, curriculum guides, and text books of grade 12 physics and chemistry units on physical thermodynamics and chemical thermodynamics respectively before the experiment. In addition, I had to interview secondary physics and chemistry curriculum specialists at the ministry of education to understand that whether the curriculum is really constructivist or not. The new curriculum was introduced without proper training for the secondary school teachers and was not implemented as

intended when I was in school for my research in 2010. This created the opportunity to test my model without violating the curriculum of the school. Even then the new curriculum was not purely constructivist and the authors did not mention any of conceptual change strategies, except some general learner-centered/ constructivist methods, to be used in teaching both physical thermodynamics and chemical thermodynamics units of grade 12. The evidences required for the above statements are shown in the sub-sections which follow this section.

3.8.1 Some Pitfalls of the Existing Secondary Physics Curriculum

There were four factors, but not necessarily limited to, considered for content evaluation of Grade 12 physical thermodynamics Unit. The factors are: (1) appropriateness of material(see the criteria in Appendix G); (2) presentation and organization of material; (3) Teacher's Guide(TG) and Curriculum Guide(CG);and (4) accuracy and up-to-datedness of information. In addition, I will provide content evaluation summary for curricular documents and finally, based on the foregoing/above evaluation recommend whether the unit of Grade 12 thermodynamics need major or minor revisions.

For question three of Appendix G, which demands that materials takes into account diversity of cultural, religious, economic and family backgrounds of treatment group students, the research and hence the authors of the unit on thermodynamics were concerned with factual, procedural, and conceptual understandings irrespective of their diversity along the above factors and therefore they are not applicable. Similarly, for question five of Appendix G no separate provisions were made regarding gender while writing the content of the unit of thermodynamics. The authors did not make a balanced approach to gender issues. Question six demands integration of positive values, while the authors did not make any connection to these values. In addition, authors did not mention what care should be taken while doing practical's in Physics.

The authors wrote on page two of Grade 12 Physics text book, "Physicists are reductionist in approach: that is, to reduce the world around us to more simple, more fundamental situations that allow us to use the basic laws to solve problems." They clearly declared the underlying philosophy of Physics, as a quantitative science which seeks generalization based on specific instances. By using the word 'reductionist' they gave the impression to their students that Physics is always inductive in general but science also involves hypothesis testing which is deductive in approach. Such statements are misleading in providing the true picture of Physics. No mention of student misconception was made in the unit. The authors defined **Caloric** as 18th century conception of heat which was "an invisible, massless fluid running 'downhill'". On page nine, some mention of heat as a substance was made. "A substance has mass; some students think heat as a transfer of substance." The authors did not distinguish between the

caloric ($m=0$) and heat as a substance ($m\neq 0$), even though both were wrong. Sufficient explanation should have been given about the nature of heat.

On page 11, it is conceptually wrong to write the first law as $\Delta U = \Delta Q + \Delta W$; this gives the impression that Q and W are state functions while they are process functions. It must be written as $\Delta U = Q + W$. Again internal energy was not clearly defined, at one place in the text they defined it as total mechanical energy of molecules, at the other place they defined it as sum of energy entering the system as heat and work done. Therefore, which of the two definitions the student should take is a confusing matter. This is a source of great misconceptions even in advanced textbooks on thermodynamics. Author(s)-induced misconceptions last longer as most students are not critical about what they learn even when constructivist/conceptual change strategies were applied.

On page 12, for isothermal and adiabatic processes the concept of heat reservoir/bath was not used. The delta was still used in all varieties of the first law throughout the unit for process functions. Explanations should have been given regarding how process functions can be related to state functions. The problem of exact differentials and inexact differentials propagate in the whole of physics content areas, even though it is not as serious as in thermodynamics.

On page 13 also the reduced form of the first law of thermodynamics was written using work as a difference between two points and the operator delta was used. The authors mentioned that work is an ordered process while heat is a random process. But the authors did not elaborate on what they mean by ordered and random process and at the same time they did not relate to the concepts of the first law of thermodynamics. On page 13 the authors wrote, that "the only isolated system in existence is the entire universe", for which $\Delta U = 0$. If so where did all the energy come from originally? They raised a good conceptual question but a hint or answer to this fundamental question was not given. This could have led to conceptual change strategies which provide correct conceptions of internal energy at last. Discussion activities mostly asked conceptual questions but lack clear instructional strategies for the discussions such as RPC of CAPs with clear cut procedures. Review questions at end of each section mix both procedural and conceptual questions but in most cases they are purely procedural. There are no factual or conceptual questions, for example, on page 30, 36 and 48. The authors did follow combined strategies which are not purely constructivist. And specifically they did not follow conceptual change strategies based on models such as: OCM, CRKM, CAMCC, etc. which already exists in the literature.

Procedures are clearly indicated for some examples, see page four, where what to do at each step is provided. On pages 20, 23, 29 and 45 procedural clarity for examples on these pages is decreasing. Even the objectives are not clearly balanced between the conceptual and procedural ones (see the key words for all objectives of all sections). In objectives words like apply, solve, calculate, etc., clearly showed procedural objectives whereas words like define, differentiate, describe, explain, identify, distinguish, show, etc. clearly showed conceptual objectives. Tables 1.1, 1.2, 1.3, show factual understandings used for procedural problems while table 1.4 and 1.5 show purely conceptual summaries of thermodynamic processes and cycles of engines respectively.

The material in the unit did not show the development of higher cognitive skills such as: critical thinking, creative thinking, problem solving, conceptual change and individual difference. The material does not show constructivist conceptual change strategies. Learner progress was not adequately checked and social skills were not adequately developed using constructivist strategies. Lacks smooth flow of ideas and activities within and from lesson to lesson. The material did not adequately check learner competencies. The resources mentioned in Teacher Guides (TG) and Curriculum Guides (CG) were not available in schools in order to develop lessons as claimed by the so-called constructivist curriculum. The methods used in Teacher Guides and Curriculum Guides are: lecture, discovery, discussion, questioning and problem solving. The methods are not purely constructivist as demanded in the text book. There are no objectives on the section on "kinetic theory of gases" in CG while the content is in the text. There are no affective objectives in the CG. In the CG, for isobaric, isochoric, isothermal, first law of thermodynamics and molar heat capacity of gases sections no teaching method is indicated. On pages six to seven of TG combined methods are used, both teacher-centered and constructivist methods are shown and the teaching strategies and the curriculum are not purely constructivist as claimed by the author(s) of the thermodynamics unit. Similarly, for sections on second law of thermodynamics, heat engines and refrigerators, teaching methods are not clearly identified. For kinetic theory of gases, the teaching methods used are experiments, demonstrations, and project works and are related to several websites. Materials mentioned in CG correspond with those in text but not available in school. Therefore, the so-called constructivist curriculum was not implemented in schools as intended. The authors did not take into account the reality of Ethiopian schools while developing the secondary school science curriculum. The authors wrote, the enthalpy equation as $\Delta Q_p = \Delta U + P\Delta V$ at $P = \text{constant}$ and was not labeled as **enthalpy**. The proper symbol for enthalpy is H . Enthalpy is a process function like heat and work but still the authors used delta which give the impression that it is a state function. Factual, grammatical, computational, and obsolete information are rare in the unit. But errors in illustrations, diagrams, figures, etc. are there. In figure 1.2, the space between the hot molecules should have been a little bit apart. Figure

caption does not match figure on page three. In figure 1.42 on page 45, figure caption does not match the diagram-converting all the heat to work is forbidden by the second law of thermodynamics but there must have been a thin arrow down ward from “hot” to “cold” reservoir. All discussion activities are not given clear strategies and are too general. What they do in the discussions is not clearly indicated as in Grade 12 Chemistry unit three on chemical thermodynamics, for example.

Table 3. 2: Documentary analysis summary for grade 12 Physical Thermodynamics unit (MoE, 2010:pp. 1-50)

Page & Paragraph Number	Classification & Description of Error	Recommended Correction or Revision
Page three, paragraph two	Illustration error	Redraw ‘hot-molecules’ diagram by increasing space between molecules.
Page seven, paragraph two	Gibbs free energy not included in relation to phase equilibrium.	Define ΔG and derive Clausius-Clapeyron equation.
Pages 9,11,12,13,14,15,16,17,20 and 40	Error in not distinguishing ‘state’ and ‘process’ functions.	The first law should be written as $\Delta U=Q+W$, using delta in front of Q and W gives the wrong impression that they are state functions.
Page 17, paragraphs three and four	Lack of naming correctly the equation	Define $\Delta Q_p=\Delta U+P\Delta V$ at $P=\text{constant}$ as enthalpy $\Delta H=\Delta Q_p$.
Page 16, Figure 1.14	Did not distinguish adiabatic curves from isothermal ones conceptually.	Explain why adiabatic and isothermal P-V diagrams looked almost the same.
Page 12, paragraph two	Heat reservoir concept not used for isothermal process.	Small system in contact with very large system/heat reservoir should be used in explaining isothermal process.
Page 45, Figure 1.42, paragraph two.	Error in diagram drawing	Redraw by adding a thin arrow to a cold sink from engine.

Note: Sign conventions for Q and W were not given in the Physical Thermodynamics unit.

And this unit requires major revision along with CG and TG for this unit. Therefore, the newly introduced physics curriculum is not purely constructivist at least as far as unit one of grade 12 physics is concerned. Even then not all constructivist strategies are conceptual change strategies. Conceptual change strategies are not explicitly shown in the new secondary physics curriculum.

3.8.2 Some Pitfalls of the Existing Secondary Chemistry Curriculum

The factors and document evaluation summary will be presented for Unit Three of Grade 12 Chemistry. Table 8.7 shows the document evaluation summary. Unit Three on Chemical Thermodynamics started on page 118 and ended on page 156 of Grade 12 Chemistry text book, spanning 39 pages. The ratings of the material is relatively good on ‘presentation and organization of material’ than on ‘appropriateness of material’. Unlike Grade 12 physical thermodynamics Unit, the authors of chemical thermodynamics unit

related it to Grade 11 chemical kinetics topic. Physical thermodynamics did not give duration/ Δt required for thermodynamic processes, but chemical kinetics and chemical Thermodynamics did. On page 119, start up activity, starts section one with group discussion and ask students to write a short report and present it to the class. A constructivist strategy is used. On page 21, what was called "process function" in physical thermodynamics has been called "path function" in this Unit causing a possible confusion in the usage of terms. To learn a concept means to infer its general definition from a number of specific examples of it. A number of examples and activities were given to enhance the learning of concepts. Functions which depend on path (process) are called path functions and as we have seen in physical thermodynamics on Q and W, these were not clearly given. On page 123, for the first law of thermodynamics both conceptual and procedural objectives were given. Isothermal processes were explained in relation to heat reservoir (heat bath), which were not explained, in a similar way in physical thermodynamics Unit. In conceptual activity 3.3, on page 123, regarding pumping air into a bicycle tire result in warming of valve stem. From where does this heat come? This is a good conceptual activity.

Internal energy's symbol was U in physical thermodynamics, but it's symbol is E in chemical thermodynamics. This causes confusion for the students, as authors of the two units are not consistent regarding the use of symbols. Horizontal integration on the use of symbols is lacking. But in chemistry, the state function nature of internal energy is more explicit than in physics unit as $\Delta E = E_{\text{final}} - E_{\text{initial}}$. On page 124, motions of molecules of various types are exhaustive but not explicit. It should state translational kinetic energy of molecules, rotational kinetic energy of molecules, vibrational kinetic energy of molecules and movement of electrons within molecules. It also stated attraction and repulsion between molecules, attraction between electrons and nuclei in molecules, repulsion between electrons in molecules and repulsion between nuclei in molecules for the potential energy component of mechanical energy. The potential energy component was exhaustive and explicit. In activity 3.4, on page 124, both procedural and conceptual understandings were checked. Heat is defined as energy transfer when there is temperature gradient. When there is thermal equilibrium, there is no heat transfer.

Table 3.1 lists specific heat of common substances which gives factual understanding. This is followed by example 3.1 and exercise 3.1 which are procedural and uses the facts in Table 3.1. Therefore, the orders in which the three types of knowledge should be taught looks like: factual knowledge followed by conceptual knowledge and finally procedural knowledge. Both factual and conceptual knowledge are required to correctly solve procedural knowledge problems. The author of Chemical Thermodynamics unit was very cautious because he never used delta (Δ) for W and Q which was the major source of misconceptions in many thermodynamics books. The author also provided a sign convention for work. In

expansion, W =negative, $W=-P\Delta V$, as $\Delta V>0$ or positive. For compression, work=positive, $W=-P\Delta V$, as $\Delta V<0$ or negative. This part was clearly explained with the help of beautiful Figure 3.3 on page 127. Activity 3.7 on the same page asks students to list types of energy transformation they know. It asks for conceptual understanding based on empirical evidence. But the first law of thermodynamics as restatement of the law of conservation of energy was not mentioned in physical thermodynamics.

The authors of chemical thermodynamics wrote the first law of thermodynamics in a better form which does not lead to confusion about Q and W as process functions. Unlike in physical thermodynamics, they also gave sign conventions for both Q and W . Energy into the system is positive when work done is positive and heat transfer is positive and it is negative when work done is negative and heat transfer is negative. Work done on the system is positive and work done by the system is negative. Heat absorbed by the system is positive and heat given off by the system is negative. These sign conventions are used in Example 3.2. If this example were in physical thermodynamics, students would have difficulty applying the first law of thermodynamics. Unlike in physical thermodynamics, the authors defined enthalpy as heat absorbed or released at constant pressure. In general, the chemical thermodynamics unit is carefully written compared to physical thermodynamics unit. However, it is mostly quantitative and high light procedural and factual understandings with less conceptual understanding. Therefore, all the three kinds of knowledge need to be balanced meticulously in this unit. The teaching strategy they suggested is also constructivist in most cases even though it lack variety and monotonous method was used throughout the unit. Mostly they used small group discussion followed by whole class discussion which includes writing of a short report and presentation to a class. However, no clear conceptual change strategy was used.

Resources mentioned in the CG were somehow sufficient and mostly available in the school for developing lessons. In TG, the teaching methods were: gapped lectures, cooperative/collaborative learning, group discussion, presentation, demonstration, experiments, concept map, questioning, spider diagram, visualization, brainstorming, etc. The methods were mostly constructivist but not all of them. For example, gapped lectures and demonstration are not constructivist methodologies. Therefore, we can say that both units of grade 12 physical science were designed to be taught in a combined strategy but not as claimed by MoE curriculum experts that the curriculum is purely constructivist.

Table 3. 3: Documentary analysis summary for grade 12 Chemical Thermodynamics unit (MoE, 2010: pp 118-156)

Page and Paragraph Number	Classification and Description of Error	Recommended Correction or Revision
Page 121, last paragraph	Organizational error for not using table to compare open, closed, and isolated systems.	Economical and descriptive to compare those systems in a Table. A paragraph for each does not appear good.
Page 123, last paragraph	Internal energy U in Grade-12 Physics Unit 1, changed to E here which shows lack of horizontal coordination.	Use same symbols in Physics and Chemistry to avoid confusion.
Page 124, second paragraph	Conceptual error, kinetic energy (K.E) not as explicit as potential energy (P.E).	K.E must be decomposed to Translational, Rotational, and Vibrational K.Es of molecules
Page 130, last paragraph	Conceptual error for not mentioning origin of $\Delta E = Q - P\Delta V$	Write as, by first law of thermodynamics, $\Delta E = Q - P\Delta V$
Throughout the unit	Short paragraphs are used (grammatical errors)	These short paragraphs are not attractive way of writing. Similar paragraphs must be merged.
Throughout the unit	Diverse traditional and constructivist strategies mentioned in CG and TG are not used in the text (pedagogical error).	Use varied constructivist strategies which can foster conceptual change in addition to fostering procedural understandings.
Throughout the unit	Procedural and factual understandings are dominant (pedagogical error).	Balance factual, procedural, and conceptual understandings.
Throughout the unit	Discussions were not based on misconceptions and ways of alleviating them (Lack of science pedagogy).	Base discussions around misconceptions and ways of alleviating them when using conceptual change strategies.

3.8.3 Views of Secondary Science Curriculum Experts about the New Curriculum

The curriculum experts at the ministry of education responded to my interview questions as shown in Appendix J. The summary of their response in relation to the context of the research is given as follows. Both chemistry and physics curriculum experts said that the content/subject matter for secondary science is based on international standards and experiences. In addition to best practices, they used the principle of minimum learning competency in selecting content for the curriculum. The Education and Training Policy (1994) guided the development of curriculum and constructivist learning theory was found to be the best learning theory for learning science. Constructivist learning theory was selected because it participate learners in the process of knowledge construction. The drawback of this new curriculum was that teachers were not well trained in the implementation of constructivist curriculum. In the academic

year 2010/2011 when it was first introduced to secondary schools, the teachers simply used the traditional methods of teaching because of lack of training in constructivist methods of teaching. This created a conducive environment for my research as I wanted to compare constructivist conceptual change strategies with traditional transmission of information strategies without violating the school curriculum for both the comparison and experimental classes. Both chemistry and physics curriculum experts confirmed that training should have been given before the curriculum was dispatched to schools (see Appendix J).

The curriculum experts emphasized that learners construction of knowledge and drawing meaning out of it is one advantage of constructivist curriculum. They asserted that the traditional curriculum is changed because rote and passive learning is not effective for learning science. The experts said that instructional strategies which work with limited resources were selected during curriculum development process. A study on Technology Faculty of Addis Ababa University has shown that lack of resources which does not fit the surging number of students undermined the use of constructivist strategies and continuous assessment methods (Shimeles, 2009). And this affected the quality of education while offering technology courses. Similarly, in Ethiopian secondary schools lack of resources for learning can undermine the use of constructivist, conceptual change strategies.

They also said that there is no exact sequence in which factual, procedural and conceptual knowledge can be taught. The curriculum lacks conceptual change strategies to alleviate students' misconceptions in thermodynamics. Not all constructivist strategies are conceptual change strategies. Conceptual change strategies are specific kinds of constructivist strategies which are designed to overcome pre-conceived non-scientific conceptions.

3.9 Conclusions

The above discussions of various learning theories have shown that the age-old debate of Plato's rationalism and Aristotle's empiricism as means of acquiring knowledge has not yet been resolved. I believe that the integration of personal rational thinking and social interaction as an empirical means of generating knowledge is the only way forward in arriving at a monist philosophy of education. Constructivism was monist in its philosophy when first launched in 1970's but as time goes on sects appeared within constructivism and it fell back into Cartesian dualism it tried to overcome from the outset. The two prominent sects are radical constructivism and social constructivism which are pulling and confusing curriculum developers in different directions. This resulted in lack of one pragmatic and monist philosophy of education from which consistent curriculum decisions can be made. Neither of Plato's rationalism nor Aristotle's empiricism which are still inherent in radical and social constructivism

respectively is separately effective. The German philosopher Emanuel Kant known for deeply analyzing the two categories of knowledge acquisition came up with his own a priori and posteriori knowledge generation in which he finally concluded that the only viable means of knowledge acquisition is through the synergy of rationalism and empiricism. The similarities of learning theories outweigh their differences. Therefore, it is better to work out a functionally unified symmetric learning theory which balances personal formation of concepts with social formation of concepts. As shown in Figure 1.1 of Chapter one, the spiral is used to unify the two categories of learning theories along the axis of learning and this is designed to be experimentally tested in science classrooms.

The new secondary science curriculum is not purely constructivist as there are methods which are teacher-centered in the curriculum guides. The curriculum is also not clearly showing whether it is using a dualist or monist philosophy of education. Whether the authors used radical constructivism or social constructivism or some combination of them is not clear from the curriculum documents. Explicit conceptual change strategies were not used in the new secondary science curriculum.

CHAPTER FOUR: MODELS OF CONCEPTUAL CHANGE

4.1 Introduction

In this chapter I will try to discuss the various models of conceptual change so that comparisons will be made with the SCSMCC as integrated model of conceptual restructuring and conceptual change. This research tries to present and discuss this proposed model of conceptual change developed using extensive literature survey of conceptual change research. The SCSMCC as holistic model which I consider a "hot" model not only incorporates conceptual change but also includes changes in motivation, attitude, perceptions(beliefs) about socio-cultural context. The process of knowledge generation is modeled as interplay between cognitive and socio-cultural factors. Many authors suggested such an interplay as a future for conceptual change learning while very few of them considered such bridging as a futile attempt because the two categories are so extreme. I personally believe and agree that a synergy of the two categories of learning theories is possible and the only way forward in conceptual change learning. What makes my research work and thus my model original is that many of the researchers which suggested that a bridge can be built between the two river banks of the metaphoric theoretical river never conceptualized the type of bridge in unifying the cognitive perspectives and the socio-cultural perspectives. The spiral inside the conical helix continually touching the cognitive and the socio-cultural axes creating a series of nodes and revolving about the central axis of learning is one such conceptualization of the bridge. The spiral is simply the geometrical embodiment of the interplay suggested by many researchers of conceptual change between the two categories of theoretical perspectives. And hence the spiral serves as a bridge between these two categories of theoretical perspectives. CAPS strategies from which my RPC was developed are also discussed in this chapter.

The SCSMCC as integrated model of conceptual change also provided its six phases of each cycle of the spiral and the way it is applied both inside the classroom and outside the classroom. The six phases of SCSMCC as holistic model dressed with the method of 'Reasoned Persuasive Collaboration' (RPC) are illustrated with an example from Thermodynamics. If in one cycle (the initial cycle) conceptual change is not achieved in the classroom, similar cycles can be initiated outside the classroom to achieve it. The model also showed that at the source of the metaphoric theoretical river, the banks of the metaphoric theoretical river coalesce into one. For any new topic introduced to the learner by the teacher, there is no difference between what is cognitive and what is socio-cultural and the difference emerges only after the banks begin to appear. And hence this new model cannot believe in the primacy of either people starts learning using their mind as cognitivists/rationalists would like to conceptualize it or begins learning in a social plane as social constructivists/empiricists would like to conceptualize it as there are no differences

in the initial point of learning between the two. The model also showed that as a person gets matured in education and experience, the cognitive and the socio-cultural aspects of learning continue to diverge. Children are more social than adults and at the same time more selfish/individual than adults. At an adult stage, much effort is needed to reconcile individual cognition and views that are socio-culturally held. How can a highly encultured person eventually liberate him/her self from the bonds of culture and claim independence if we teach him always using, say, social constructivism? And on the other hand, how can we enculture a person who has been educated using, say, personal constructivism and become sensitive to the problems of the society and its solutions? In this chapter, I will try to show how the integrated model of knowledge change and extra rational constructs change is the best way forward.

4.2 Literature Review on Models of Conceptual Change

In this review I will try to discuss the various models of conceptual change so that comparisons will be made with the SCSMCC as integrated model of conceptual restructuring and conceptual change. Posner and associates (1982:21) were inspired by Kuhn's (1962) theory of scientific revolution as they stated that "a major source of hypotheses concerning this issue (of conceptual change) is the contemporary philosophy of science..." Their model as it accounts for only cognitive factors was labeled by Pintrich and associates (1993) as "cold" model of conceptual change as it does not account for: motivational, epistemological beliefs, attitudes (affective), and socio-cultural factors. Those later models which do account for the above factors in varying degrees were named as "warm" and "hot" models of conceptual change. I consider SCSMCC as integrated model as a "hot" model of conceptual change as it accounts for motivational, perceptual feelings or epistemological beliefs, attitudinal/affective, and socio-cultural factors.

There are a number of conceptual change models in science education. Several attempts have been made to come up with a comprehensive and original model of conceptual change. Posner and his associates (1982) developed the first model of conceptual change. These researchers based their model on Kuhn's (1962) famous book on theory change and the works of cognitive developmental psychologists such as Piaget's assimilation, accommodation, and equilibration. Pintrich and his associates (1993) called this classical model a "cold" model of conceptual change for it doesn't include motivational factors and focus only on cognitive factors. For nearly two decades this model guided research on conceptual change. Dole and Sinatra (1998) came up with a "warm" model of conceptual change which included motivational factors in addition to cognitive factors. They called their model "**Cognitive Reconstruction of Knowledge Model (CRKM)**". They raised the temperature of their model to escape Pintrich and associates (1993) criticism of the "cold" model of conceptual change. Any inclusion of motivational, affective and socio-cultural contextual factors in conceptual change instruction can raise the temperature

of a model. These factors are what Piaget called 'door keepers' in any model/theory of knowledge acquisition. The metaphoric use of the word 'temperature' and its derivatives is quite clear here. Gregoire (2003) also came up with a model of conceptual change by further increasing the temperature which she claimed to be a "hot" model of conceptual change. She added affective factors in addition to cognitive and motivational factors to her model. She called her model "**Cognitive-Affective Model of Conceptual Change (CAMCC)**". Murphy (2007) also came up with a model of knowledge and belief change. She claimed, in addition to model development, that the age old debate about the source and location of knowledge should be resolved by minimizing the gap between the cognitive and the socio-cultural (situative) sides of the theoretical metaphoric river. To decrease the gap a bridge should be built between the two river banks and this is the only way forward in conceptual change research and conceptual development should be based on interplay of both the individual and socio-cultural (situative) factors. However, she did not elaborate on the nature of the bridge that should be built.

Patricia (2007) doubted Murphy's proposal by saying that: *'bridging cognition and scioculturalism within conceptual change research: unnecessary foray or unachievable feat'*. She said that the two sides of the metaphoric theoretical river are so extreme that they cannot be bridged. Duit (1999) at the end of his analysis of conceptual change research proposed that the future of research in conceptual change should focus on using both the individual cognitive factors and socio-cultural factors for any effective model of conceptual change. Vosniadou (2007) have similar idea as that of Murphy (2007) in which she claimed that there is no way forward except to bridge the two extremes in the future for conceptual change research. Based on the above mentioned ongoing debates, I tried to fill the gap in conceptual change research by developing and proposing model of conceptual change which I called the '**Spiral Cognitive-Sociocultural Model of Conceptual Change (SCSMCC)**'. To implement this model in the science classroom, we need to use a class of pedagogical approaches, namely, the **Critical-Analytic Pedagogies (CAPs)** proposed by Murphy (2007) for such kind of research. Two of the CAPs strategies for conceptual change research she mentioned were 'Persuasive Pedagogy' (PP) and 'Collaborative Reasoning' (CR) and she claimed that these methods are empirically tested and proven fruitful. I combined these two methods and developed a hybrid method to use the synergetic effect of using combined methods. I called my method '**Reasoned Persuasive Collaboration**' (RPC) which I used in the teaching of topics found in Grade 12 science classes. This method can be dressed on to the six phases of SCSMCC as integrated model of conceptual restructuring and conceptual change.

Context reach and complex subject contents such as Thermodynamics and Mechanics can be used to test the validity of the SCSMCC as holistic model. I tested the model on Grade 12 students on topics of

Physical Thermodynamics in Physics and Chemical Thermodynamics in Chemistry. Empirical results have been showing that the model is indeed a valid one. Thermodynamics is selected because it is one of the most complex domains of Physics in which students usually feel a lot of learning difficulties. The literature shows that there is no comprehensive model of conceptual change. The selected and developed model is based on recent research works in the area of conceptual change and which is hitherto not experimentally tested but implied useful as the way forward in the conceptual change research. I added the word '**spiral**' to conceptually bridge the banks of the metaphoric river and integrated the two categories of learning theories divided based on the source and repository of knowledge.

The 'Cognitive' side argues that the individual mind is the source and repository of knowledge and under this category the following learning theories are grouped: 'Personal construct theory' of Kelly (1955), 'Radical constructivism' of von Glasersfeld' (1995), 'Cognitive constructivism' of Piaget'(1985), 'Information Processing Theory' of Simon (1989a),etc. on one hand and the ' Sociocultural'/'Situative' side argues that the social environment is the source and repository of knowledge and under this category the following learning theories are grouped: 'Socioculturalism,'(Greeno and Van Sande, 2007), 'Social Constructivism' of Vygotsky (1978), 'Social Learning Theory of Bandura' (1977), 'Situated Cognition of Lave' (1988), etc. on the other hand. Some researchers have strong doubt that the two categories mentioned above are bridgeable while others believe that this is the only way forward, the debate is still ongoing. I took the side of the latter group and wanted to spirally bridge the two sides of theories of knowledge by claiming that the source and repository of knowledge is in both and knowledge is generated in the process of interplay between the person and the socio-cultural environment.

Such interplay is modeled by a three dimensional spiral starting at the base of the conical helix and progressing around its axis which I called the **axis of learning**. The spiral touches in cyclical manner alternatively the cognitive and the socio-cultural sides on places which I called nodes in an effort to bridge the two categories of learning theories. I am not the first to use the 'spiral' in developing a learning theory model; Basiel (1998) used a spiral function for web-based construction of knowledge. From the literature, it is not very clear that whether Basiel (1998) used a three dimensional cylindrical spiral helix or a conical helix as a model for his learning theory. I used, however, equiangular three dimensional spiral of a conical helix as my model of conceptual change. Many researchers, such as Thagard (1992), Hatano (1994), Duit (1999), Murphy(2007), Vosniadou (2007), Greeno and van Sande (2007), Halldén and associates (2007) etc., have suggested that the future of good science learning is by using some kind of combination of the 'cognitive' and 'socio-cultural' perspectives. Based on these premises, I proposed

SCSMCC as integrated model of conceptual change in the sciences and began empirically testing it. As indicated earlier the spiral model is hailed as a superior method of teaching science.

There is the debate whether knowledge is to be looked upon as personal and residing within the individual or if it is embraced within discursive practices and cultural tools (Hallden, et al, 2007:38). Socioculturalism puts knowledge within the immediate social context and human interactions (example, Social constructivism). Cognitivism gives primacy to the individual mind as both the constructor of knowledge and its repository (example, radical constructivism). In socioculturalism "knowledge" is viewed as between rather than within individuals, with conceptual understanding and conceptual growth portrayed as functions "accomplished by activity systems and communities of practice" (Greeno and Van de Sande, 2007). The bridge that connects the individual to the social construction of knowledge must be built. The bridge that eventually connects the cognitive and socio-cultural sides of the epistemological debate must be built. In the bridging process, I start with engaging the 'door keepers' phase and move on to individual critical and analytic thinking phase and move towards small group sharing phase of what is critically thought and analyzed ; through selected spokes person move to whole class discussion phase facilitated by the teacher and come to a consensus by restructuring their concepts and once more the individual student looks back and critically reflect on by jotting down how the deconstruction of initially held conceptions and reconstruction of current conception went on, in which s/he spirally rethink again individually which leads to still another higher sets of sharing knowledge; the process goes on upwards on knowledge accumulation and application ladder of the spiral with increasing depth(vertical transfer) and breadth(horizontal transfer) which leads to more adaptive expertise. Finally, the teacher provides well-thought of conceptual questions and problems that the students need to answer and solve checking whether conceptual change has been achieved before the class ends. If conceptual change is not achieved in one class period, the geometrical embodiment of the interplay between the cognitive and socio-cultural which I called the spiral will initiate another cycle until conceptual change is achieved.

4.3 The Classical/ "Cold" Conceptual Change Model

Kuhn's preconditions of scientific revolution are: appearance of anomalies that eventually lead to scientists' dissatisfaction with old paradigm, the appearance of a new paradigm that provides scientists with a choice, and the merits of a new paradigm such as solving more problems, accurate predictions, closer match with subject matter and more compatibility with other specialties. Paralleling Kuhn's conditions of a scientific revolution, Posner and associates (1982) proposed cognitive preconditions of conceptual change: dissatisfaction with the old conception, the intelligibility, plausibility, and fruitfulness of the new conception. Posner and his associates (1982:212) asserted that "learning is a rational activity" declaring that their model is purely a cognitive one. Dissatisfaction arises from mismatch of existing

mental structure of learners and their school science. The aim of school science is to achieve deep understanding. The "cold" model does not address affective factors such as: interests, feelings, values, goals, attitudes, etc. Piaget asserted that affection is the door keeper and controls whether or not assimilation, accommodation, and equilibration happens during learning experiences. Traditional learning is passive and does not result in deep understanding.

Posner and associates (1982) model also lack socio-cultural factors as it emphasizes personal cognition and takes for granted that all learning takes place in individual's mind. But Thagard (1992) concluded that conceptual change learning is both an individual cognitive activity and a social construction. In a process of reconstruction of knowledge, Piaget considers social interaction as a requirement to construct social knowledge and as a resource for cognitive disequilibrium. For Vygotsky (1978:57), however, all higher mental operations/functions originate from social relationships/interactions. Vosniadou (2008: xix) considered conceptual change both as an individual, internal cognitive process and a social activity that occurs in a complex socio-cultural world. Piaget insisted that children individually invent knowledge and also use social interaction in knowledge acquisition. Vygotsky (1978), however, insisted that knowledge is the internalization of social/cultural relationships by mind-in-society. Leont'ev (1981:57) asserted that "the process of internalization is not the transferal of an external activity to a pre existing, internal plane of consciousness. It is the process in which this plane is formed. Tao and Gemstone (1999) found out, in their experimental study, that when co-construction was accompanied by personal construction, conceptual change becomes stable in time. Only when the child personally makes sense of the new understanding, conceptual change becomes stable over the course of time. Learning, thus, involves not only the integration of new information but also the reconstruction of existing knowledge representations. Such restructuring of knowledge is known as conceptual change (Vosniadou, 1999).

Strike and Posner (1992) recognized the importance of the affective, situational, and motivational factors that influence or even determine conceptual change. Pintrich and his associates (1993) also linked cognition and motivation in conceptual change learning. They labeled "cold" conceptual change, perspectives which focus on rational, cognitive factors to the exclusion of extra rational or "hot" constructs. Cognitive factors in conceptual change, studied by Chi (1992), Thagard (1992), and Vosniadou and Brewer (1987; 1992), considered the breadth and depth of the changes in students' knowledge representations. It was found out that misconceptions are barriers to knowledge restructuring. Cognitive developmentalists such as Carey (1985; 1992) explained how children's conceptions are basically different from adults/scientists. The design of instruction to foster conceptual change was studied by Posner and his associates (1982), how students' knowledge seems to resist change even when instruction is designed to change their preconceptions. They found a parallel between Kuhn's scientific

revolutions and the process of knowledge restructuring. According to Strike and Posner (1992:162), dissatisfaction gives affective reason to change existing knowledge.

4.3.1 Criticisms of the Classical Conceptual Change Model

One of the criticisms against the classical model that came in the 1990s is from the angle of situative view which is that conceptual change should not be taken as an individual, internal, cognitive process but rather as a social activity which occurs in a complex socio-cultural world and that the situational, cultural, and educational contexts should be considered (Caravita and Halldén, 1994; Hatano, 1994; Säljö, 1999). Others criticized it for failing not to consider motivational and affective factors (Pintrich et al., 1993; Dole and Sinatra, 1998). Smith and associates (1994) criticized the classical model in that misconceptions are not always well formed and/or resistant to change. Chinn and Brewer (1993); Smith and associates (1993); and Vosniadou (1999) criticized the classical model in that cognitive conflict is not a successful instructional strategy for producing conceptual change as students patch up local inconsistencies in a superficial way. Also Spada (1994) etc. criticized the “cold” model in that science learning does not require the replacement of “ incorrect” with “correct” conceptions, but students ability to hold various view points and understand the use of different conceptions depending on the context of use, and so on.

4.4 The Cognitive Reconstruction of Knowledge Model: a “Warm” Model

The “cold” model clearly defined the role of the teacher, but it does not clearly state the role of the learner in conceptual change. According to Dole and Sinatra (1998), cognitive conflict is often not enough to induce change. Based on perspectives from Social Psychology, Cognitive Psychology, and Science Education, Dole and Sinatra (1998) developed “**the Cognitive Reconstruction of Knowledge Model**” (CRKM) which incorporated motivational constructs into the complexity of conceptual change learning. Views of attitude change and persuasion was borrowed from Social Psychology, particularly the Elaboration Likelihood Model (ELM) of Petty and Cacioppo (1986). The ELM is a dual process model of attitude change. Dual process model take a central and a peripheral route to change. The central route is taking systemic/deep processing route which can result in change. Motivational influences on attitude and belief change are described by ELM. ELM also incorporated some aspects of the “cold” model.

Structural changes in knowledge representation are due to the works of Cognitive Developmental Psychologists. The CRKM describes how learner and message characteristics interact. The depth of cognitive engagement ultimately determines conceptual change. Message characteristics refer to features of instructional content or persuasive discourse designed to effect change. These two together show the degree to which the learner finds the message comprehensible, coherent, plausible, and rhetorically compelling. If message lacks even one of them, conceptual change will not occur. This model emphasizes

the importance of background knowledge and motivational factors. Strength, coherence, and commitment are aspects of learner's existing knowledge which can produce conceptual change. Strength refers to conceptual development of learners. Strong ideas have rich representation and well-established relationships with other ideas may not change. Coherence refers to stable conceptual ecosystem (Posner et al., 1982) or conceptual coherence of ideas (Thagard, 1992). Less coherent ideas can change. Commitment to an idea influences the process of knowledge change. Learner's weak commitment may not result in change. These are aspects of background knowledge polished by motivation.

The degree of commitment to ideas has relationship to person's epistemological beliefs. The belief about knowledge is as constant and stable or dynamically changing in a constant manner. The constancy of knowledge belief creates resistance to knowledge change (Sinatra et al., 2003). The motivational factors are: dissatisfaction, personal relevance (capture motivation stemming from-interest, emotional involvement, self-efficacy, and having stake in the outcome), and social context. Pintrich and associates (1998) identified classroom contextual factors which influence learner's motivation and cognition. They also identified motivational factors which promote change, such as: interest, self-efficacy, and importance (having stake in the outcome). In SCSMCC the motivators are: arousing curiosity by engaging the door keepers, personal curiosity/need for cognition, personal relevance and reflection (which includes-interest, emotional involvement, self-efficacy, and having stake in the outcome), and socio-cultural context.

Pintrich and associates (1998:178) explained how motivation interacts with the context, when they stated "classroom contextual factors ...can influence students' motivation and cognition and can either facilitate or hinder the potential for conceptual change". Petty and Cacioppo (1986), however, took curiosity/need for cognition as personal characteristic of the learner that serves as a motivator to engage with the message. In accordance with the last authors, I took for my model "personal curiosity" as a motivator particularly during "Initial Personal Thinking" Phase. Personal curiosity and intrinsic motivation are key facilitators of conceptual change. Pintrich and associates (1993) did not mention "curiosity" as a motivator. But the ELM took "need for cognition" or "curiosity" as a stable personality trait that motivates. Dole and Sinatra (1998), however, took "control beliefs" as personal trait and emphasized the situational aspect of those beliefs. The CRKM explains how learners characteristics (background knowledge and motivation) interact with message characteristics (comprehensible, plausible, coherent, and rhetorically compelling) facilitate conceptual change.

Only after the learner comprehends the message that conceptual and attitudinal changes will occur. If the message lacks the stated characteristics, the learner will not be motivated to process the message. The interaction between message and learner features creates an engagement with the learning task. The

CRKM, therefore, hypothesized a continuum of engagement from low cognitive to high metacognitive engagement. Low cognitive engagement results in surface understanding. High metacognitive engagement results in deep understanding, a process which includes metacognitive reflection. Strong conceptual change can only occur if learners are engaged in high metacognitive processing. The CRKM is not a linear model, the learner iteratively revisits the learning task over repeated exposure to content in classroom and outside classroom using discussions, reading, listening to talks on content, engaging in activities related to content, etc. The SCSMCC as integrated model is not also a linear model rather it is a curvilinear model as shown by a spiral around a conical helix. The learner needs to revisit the content over repeated exposures in both inside and outside classrooms. By clearly showing the route of knowledge acquisition the SCSMCC as integrated model is better than CRKM. The CRKM did not model how the repeated exposure should look like. And also the socio-cultural context is less emphasized compared to the cognitive aspect and they did not show how the two categories of theories can be related. Motivational constructs exist in description of learner background knowledge and the engagement continuum. Therefore, the CRKM reflects a warmer view of conceptual change as envisaged by Pintrich and associates (1993). CRKM used the motivation as a dummy index which cannot change concomitantly with knowledge.

4.5 The Cognitive-Affective Model of Conceptual Change: a "Hot" Model

Gregoire (2003) came up with a similar model to CRKM, but with one notable additional difference, the inclusion of affective constructs such as anxiety and fear. Practicing teachers' usually resist the adoption of reform oriented curricula which contradicts their current beliefs about instructional processes. Gregoire (2003) stated that stress and threat appraisals "happen automatically before characteristics of the message are seriously considered". This is the reason why I used my initial phase of engaging the door keepers. Unless the students are motivated, their interest aroused and believe in what they learn, meaningful learning cannot happen. 'The CAMCC is developed to provide an explanation about the resistance beliefs pose against innovation in curriculum and instruction. A message will not be fully processed if affective appraisals dismiss it. CAMCC was inspired by views on conceptual, attitudinal, and belief changes. Gregoire (2003:163) compared CRKM with CAMCC as that "the CRKM is considered a *warm* model of conceptual change. I propose, however, that the new model advanced in this article is truly a *hot* model of conceptual change". The similarities of the two models are: the models describe the same cognitive and motivational constructs such as –background knowledge, information/message processing ability, and self-efficacy. They both used persuasive pedagogy as an instructional strategy. Teachers who believe that they have a stake in the outcome of the innovative curriculum are highly likely to process the message which is similar to CRKM's personal relevance. Personal relevance is even similar to Pintrich and his associates (1993) notion of students' perception of the importance of the topic. The CAMCC, by

providing greater role for affective constructs, requires a high level of emotional engagement using stress and threat appraisals.

Latest reform efforts are influenced by anxiety, fear, and copying mechanisms of teachers which determine how teachers view the message. It is the inclusion of affective constructs which raised the temperature of CAMCC. The CAMCC also goes beyond CRKM regarding goals. Goals have specific roles in CAMCC as compared to CRKM. Approach or avoidance goals are examples in CAMCC. Teachers adopt avoidance goals if they feel the reform as threatening. If reform is taken as a challenge rather than a threat then they adopt approach goal which lead to a route of conceptual change. Understanding how affective appraisals happen can generally lead to a better design of conceptual change instruction. In Pintrich and associates (1993), it is noted that cognitive, affective, and motivational constructs interact in a manner that either inhibit or facilitate change. The preliminary results of SCSMCC have shown that changes in cognitive, motivational, and attitudinal changes and perceptions about learning strategies have been witnessed. CAMCC involve knowledge and belief change, while CRKM involve knowledge change only.

Roles of epistemological beliefs, interest, and achievement goals on conceptual change have been studied by many researchers (Andre & Windschitl, 2003; Mason & Bascolo, 2004; Linnenbrink & Pintrich, 2002; 2003). All researchers have shown that hot constructs play a mediating and even determining role in conceptual change. That is why I tried to include cognitive, affective, motivational, and sociocultural contextual constructs in SCSMCC to make it a truly "hot" model of conceptual change.

4.6 Arguments about the Source and Location of Knowledge in Conceptual Change Research

There is ongoing debate about the source and location of knowledge (Chinn & Malhotra, 2002; Patricia, 2007). Two contrasting epistemological perspectives about knowledge acquisition and change are: the socio-cultural perspective and the cognitive perspective. The socio-cultural perspective regards social experience as the principal source of knowledge while the cognitive perspective emphasize the individual's mind and reasoning as the primary source of knowledge. **Murphy (2007) argued that both socio-cultural and cognitive influences are critical catalysts in conceptual change and that integration of these components is vital to learning** (my emphasis). She also asserted that relations between belief and knowledge in the conceptual change process emphasize two instructional approaches which effectively integrate the socio-cultural and cognitive dimensions of change.

4.6.1 The Interplay of the Socio-cultural and Cognitive Components in Conceptual Change

Researchers in socio-cultural perspective category assert that knowledge development and change is understood as a process that is “socially constructed and culturally shaped” (Kelly & Green, 1998: 148). This happens within a particular community (Driver et al., 1994; Kelly et al., 1993). Kelly and Green (1998) defined the community by the practices, tools, artifacts, signs and discourses employed by the group during meaning making. In (Ibid: 147-148), the nature of the discourse is a function of time as does shared, distributed knowledge within the group:

That is, as members interact overtime, they shape and are shaped by discourses... develop situated definitions of what it means to be a scientist, reader, writer, a group member among other roles and relationships... and constructs local knowledge... that becomes common knowledge within the group or class...(Kelly and Green, 1998: 147-148).

Thus, the source of knowledge, according to empiricists/socioculturalists is external to the individual knower. Some researchers such as Souza & Lima (1995) took a moderate stance of socioculturalism, in which they claimed that knowledge constructed through social participation is ultimately stored in the mind of the individual. Carey (1985), in contrast, advanced a stance of cognitive/rational perspectives, the process of construction of knowledge involve mental representations and informed naïve theories of the external world and structure as well as coherence of those representations among themselves in the mind of the individual. In cognitive perspectives, the most important point is the degree of agreement of students' mental representations about the external world with scientifically accepted representations. Murphy & Mason (2006) reasoned that individual's initial understandings or beliefs rarely match with scientifically accepted understandings of natural phenomena. And therefore, conceptual change is the process through which students gradually modify their current/initial understandings towards scientifically held understandings of natural phenomena (Hayes et al., 2003). In Platonic rationalism/cognitivism, the primary source of knowledge is the mind. In Aristotelian empiricism/socioculturalism, the primary source of knowledge is the immediate socio-cultural context.

For Greeno and Vande Sande (2007), sensory experience is not the only way of acquiring knowledge and exists/resides in the interaction. Sociocultural perspectives, therefore, take social experience as the major source of knowledge (Maria, 2000). Cognitive perspectives take the individual mind and the reasoning thereof as the major source of knowledge (Vosniadou, 2003). According to Kelly and Green (1998), despite differences in perspectives, the above two perspectives influences as critical catalysts in conceptual change and that integrating them for the sake of learning is vital. Murphy (2007) in support of the last author's views explored the epistemic views of students and the role these views play in knowledge acquisition and change. Murphy proposed a framework based on the relationship between

belief and knowledge change. The framework is believed to exist in the mind of the individual. She demonstrated that students use both social interactions and cognitive processing in forming their understandings. She proposed persuasive pedagogy and collaborative reasoning instructional strategies which incorporated the social and cognitive perspectives in the process of knowledge and belief change.

According to Murphy (2007), when beliefs which are socially enculturated are integrated with cognitively reasoned understandings concomitant changes in beliefs and knowledge can occur. As a result of these changes, she endorsed the integration of sociocultural and cognitive perspectives in order to enhance conceptual change. Mason (2001) conducted classroom research to empirically test how both belief and knowledge change can be effected. The ultimate goal of such engagement in information processing is the goal of depth in lieu of breadth (Alexander et al., 1998). In both the sociocultural and cognitive perspectives, learners consistently seek cognitive equilibrium (Chinn & Malhotra, 2002; Tsai, 2003).

According to Pierce (1958:59), beliefs are deliberate habits of action which can be conceptualized as conscious: "our beliefs guide our desires and shape our actions...The feeling of believing is a more or less sure indication of there being established in our nature some habit which will determine our actions".

According to Pierce, belief change can be initiated when beliefs are negative or when the actual practical effects of an action are different from the *expected* practical consequences. Strong negative beliefs can result in a change of understandings. The proof for change in understandings is public scrutiny and verifiability. Pierce believed in social aspect of knowledge, as:

[I]n a universe in which events are uncertain and perception is fallible, knowing cannot be a matter of an individual mind "mirroring" reality. Each mind reflects differently – even the same mind reflects differently at different moments- and in case reality doesn't stand still long enough to be accurately mirrored. peirce's conclusion was that knowledge must therefore be social. It was his most importance contribution to American thought, and when he recalled, late in life, how he came to formulate it, he described it fittingly - as the product of a group (Menand, 2001:199-200).

Understandings must be verified in public and ideas must be tested by the scrutiny and verification of classmates and teachers when it occurs in school settings (Driver et al., 1994; Kelly & Green, 1998). Alexander and associates (1998) asserted that personal experience and peer influence are quite mandatory in belief revision.

Greeno and associates (1996) defined the cognitive perspective as the view that "treats knowing as having structures of information and processes that recognize and construct patterns of symbols to understand concepts and exhibit general abilities, such as reasoning, solving problems, and using and understanding language (Ibid:18). "Situative perspective is defined as

the approach that treats knowledge as a process, an activity that takes place among individuals, the tools and artifacts that use, and the communities and practices in which they participate (Greeno et al., 1996: 20) (My emphasis)

4.6.2 Bridging the Cognitive (Personal) and Socio-cultural (Group) Sources/Locations of Knowledge in Conceptual Change Research

According to Hutchins (1995:365), “the physical-symbol-system architecture is not a model of individual cognition. It is a model of the operation of a socio-cultural system from which the human actor has been removed.” On the same page, he claims that the computer:

was not made in the image of a person. The computer was made in the image of the formal manipulations of abstract symbols. And the last 30 years of cognitive science can be seen as attempts to remake the person in the image of the computer.

On the same page, he argues that we can re-embody cognition by softening the gap between the inside and the outside, or between the individual and the context, and he goes on to claim that:

humans are adaptive systems continually producing and exploiting a rich world of cultural structure. The proper unit of analysis for talking about cognitive change includes the socio-material environment of thinking.

Although he is a socio-cultural theorist, he does not reject that knowledge can be acquired and can change. He said that the problem of cognitive science is not that humans are processors of symbolic structures, but cognitive science did not consider “how we got to be symbol manipulators and how we work as participants in socio-cultural system, rather than assume it as an act of faith” (Ibid:372). He defined learning as neither as occurring inside an individual nor happens outside during participation. Learning is:

the adaptation of structure in one part of a complex system to organization in other parts. Some parts are re-organized inside the skin. The question of individual learning now becomes a question of how that which is inside a person might change overtime as a consequence of repeated interventions with these elements of cultural structure (Ibid:290).

This synergetic definition of learning is by far better than that offered by either the cognitivists or socioculturalists. According to the argument advanced by researchers in socio-cultural perspective concepts should not be investigated as internal mental processes that “reside inside our heads” but as “elements of discourses that are used in various practices in society” (Iverson et al., 2002:79). External representations can help generate internal mental models, but when no such external representations are

available the process of internal representation or reasoning becomes very difficult. Human beings have distributed cognitive system which can reason out on the basis of both external and internal models of thought. Mental models play a vital role in our distributed cognitive system. According to Vosniadou (2001), mental models can serve the purpose of explanatory and predictive power and mediate revision of current knowledge and help in the construction of new ones. The sociocultural/situative perspective emphasizes the vital role played by cultural artifacts in assisting/facilitating thinking. Cultural factors that mediate thinking range from symbols like: language, mathematics, reading, writing, etc., to artifacts like globe, map, computers, pencils, paper, etc.

There is a debate going on about whether conceptual change and learning is more rightfully perceived through a cognitive or socio-cultural lens. Is "cognition" associated with radical constructivism (von Glasersfeld, 1995), information-processing theory (Simon, 1989a), or cognitive constructivism (Piaget, 1929)? Is "socio-culturalism" related to social constructivism (Vygotsky, 1978), situated cognition (Green, 1989; Lave, 1988)? Vosniadou (2007:56) wrote that the "main difference between the two perspectives is their position on the ontological status of knowledge". And Murphy (2007:41) stated that "sociocultural and cognitive perspectives hold two epistemologically different views on knowledge acquisition and change." Patricia (2007) contends that knowledge cannot arise solely or primarily through combination of cognitive or rational constructivism and socio-cultural practices. According to her, any attempt to use a combined perspective is futile as they are very much far apart. Where does knowledge reside? Is it in mental structures of the mind (mental models or representations) or is it in the environment or alive in group interactions (i.e., situated phenomena)?

According to Hatano (1994), "understanding is a social process; it also involves much processing by an active individual mind". Even Piaget, a personal constructivist, did not deny the importance of social factors in mediating understanding. Halldén and his associates (2007) put knowledge or understanding in the mind of the individual but give the process of knowing to socio-cultural factors. Murphy (2007) and Vosniadou (2007) took conceptual change as the process of changing both knowledge and belief. Even the socioculturalists cannot envisage a theory of knowledge or epistemology without some contribution from individual cognition. Murphy (2007) noted that mental models reflect the world external to the mind and the understandings groups construct cannot arise without thought and reflection by individual members. She also noted that the synergy of the two seemingly opposite perspectives have an excellent future for classroom instruction based on conceptual change strategy. Therefore, this illuminates the necessity of functionally unified and monist cognitive- sociocultural perspective on conceptual change.

A constructivist view does not lead to a simple, uncontested set of rules for pedagogical practice. General agreement is that students need interaction with the physical world and with their peers to stimulate meaning-making. The teacher elicits student's initial beliefs about the subject to be studied and about the nature of learning. Constructivist approaches to teaching and cooperative learning techniques can be thought of as having both personal and interpersonal components. At the same time that students become more aware of and take more responsibility for their own thinking, as they increase their understanding and appreciation of other people's thinking.

I developed standardized achievement tests used to see differences in performance of students when taught by two different methods. The study tests the validity of the proposed SCSMCC as comprehensive model in Ethiopian context. The advantages of such model-based research are: (1) the theory focuses the direction of the research. Without a theoretical model as the starting point, many studies address trivial questions or contribute nothing to the slow accumulation of knowledge. (2) A theoretical model can provide a rational basis for explaining or interpreting the results of research. Studies without a theoretical foundation often produce results that the investigator is at a loss to explain. Such studies still can help in the development of a theory, but their impact on our understanding of the phenomena being studied is much less clear and immediate than that of research that is firmly based on an already developed model of learning.

The SCSMCC teacher/educator seeks to induce cognitive disequilibrium/dissonance by setting up situations that encourage learners to question their existing beliefs and help the learners reconstruct their beliefs in valid ways. The teacher provides a platform or a topic of conflicting ideas for the learners to investigate on their own and take position. Cognitive disequilibrium is a necessary precursor of learning and learning will not take place unless explanations are sought. If our existing understandings could explain everything, there would be no need for further understanding. If new conceptualization constructed by the learner seems more plausible than the prior notion it may be accepted by the learner as a tentative replacement for the prior notion. For lasting validation and acceptance three factors must be achieved: plausible explanation, accurate prediction, and group agreement/consensus. Learning science is thus, a process of construction and reconstruction by deconstructing personal theories previously held.

Conceptual change is the problem of how concepts alter with learning and development. Conceptual change researchers did a number of attempts to bridge the polarized cognitive and situative/sociocultural perspectives. In cognitive perspective knowledge is in the minds of individuals which can be transferred to other situations. Consistent discontinuities have been observed between individuals' performance in schools and work situations. Following the formal algorithms/procedures of schools in everyday

situations is always a problem. The participants are doing much better in work situations using qualitatively different, quick, and informal procedures(Vosniadou, 2007). Lave (1988) asserted that activities done by individuals are situated in rich social and physical contexts. A view shared by Greeno (1988):

[A]n important limitation of current models and the cognitive principles that they embody is their inability to account for performance that is highly situated . . . it seems best to characterize knowledge in relation between the knowing agent and the situation . . . Current cognitive models lack this relational character (Greeno, 1988: 27-28).

In sociocultural perspective, reasoning is context-dependent and is related to marked absence of transfer of learning in school settings. Socio-cultural perspective is problematic in learning situations where transfer is observed. Therefore, if we define knowledge as participation in culturally relevant activities in socio-cultural contexts, then there is nothing stable enough to transfer from one specific situation to another. According to Vosniadou (2007), any theory that cannot explain transfer is a very inadequate theory of learning. Both the cognitive and socio-cultural perspectives agree on some invariant characteristics of the learner to make transfer a reality (Greeno, 1997:18):

1. *Learning need not be bound to the specific situation of its application; rather, it is possible for instruction to generalize from classroom to real world settings/ situations.*
2. *Knowledge can indeed transfer between different sorts of tasks.*
3. *Abstract instruction can be very effective.*
4. *Instruction need not take place only in complex social situations.*

Cognitive perspective can only make little account of transfer from school tasks to real world situations, whereas the situative/sociocultural perspective is not cable of explaining transfer altogether. However, the conceptual change approach can make some contribution to the problem of transfer(Vosniadou, 2007). Most theories of learning assume that learning is cumulative and domain general. In contrast, the conceptual change approach is a constructivist approach which assumes that knowledge is structured in domain-specific, theory-like structures, and that knowledge acquisition is characterized by theory changes (Vosniadou, 2007). The phrase 'theory-like' denotes a relatively coherent domain-specific body of knowledge which is not a scientific theory. The conceptual change approach is initially very much limited to physics education, now includes all of the sciences and also domains such as mathematics, history and psychology.

Posner and associates (1982) model is the model of theory change and cognitive conflict is a major instructional strategy for producing conceptual change and conceptual change is like a gestalt shift that happens in a spur of a moment or in a very short time interval. The SCSMCC as integrated model of conceptual change, however, took an eclectic position on the way changes occur in individuals. The change is both evolutionary and revolutionary depending on the speed of understanding of the individual learner. According to Patricia (2007), the question where knowledge comes from and where it resides creates a multidimensional epistemological space. In this space, there are theories that give primacy to the individual mind as both the constructor and repository of knowledge (example, radical constructivism). In contrast, there are theories that claim the source and location of knowledge is in immediate social context and human interactions (example, socioculturalism). The extreme learning theories taken as cognitive or sociocultural are termed as "hard perspectives." Greeno and van de Sande (2007) suggested that a bridge can be built to relate cognitive and sociocultural perspectives epistemologically. My SCSMCC as comprehensive model conceptualizes this bridge as a spiral inside the conical helix with nodes on cognitive and socio- cultural axes and revolving around the central axis of learning. Such researchers which advance a unifying perspective or moderate theories are placed by Patricia (2007) under the category of "soft perspectives." According to her, the soft perspectives do not need to build a bridge between cognitive and sociocultural orientations. For me this is simply a stance she followed to deny any relationship between the two perspectives. If they are soft they need some form of bridge to relate the two categories of theories as they have already claimed.

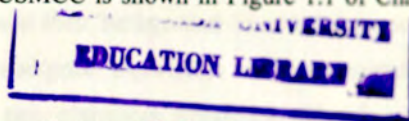
Therefore, this illuminates the necessity of a monist and functionally unified cognitive-sociocultural perspective on conceptual change. Even the socioculturalists cannot envisage a theory of knowledge or epistemology without some contribution from individual cognition. Murphy (2007) also noted that the synergy of the two "seemingly" opposite perspectives have an excellent future for classroom instruction based on conceptual change strategy. Patricia (2007), however, believed that bridging her two hard perspectives is a futile attempt. I filled this gap in conceptual change research and come up with a model of conceptual change which bridges the two categories of learning theories.

The methodology used to arrive at the SCSMCC as holistic model of conceptual change in this research is an extensive survey of literature in conceptual change research. In depth analysis of conceptual change research has been conducted in relation to the development of my model of conceptual change. Based on the survey I figured out the gap in the stated research and finally formulated the integrated model of conceptual change. Once I am convinced that my model of conceptual change is theoretically plausible, I used a quasi experimental design to test its validity on grade 12 science classrooms. Empirical results

upheld that the model is indeed a valid one. The six phases of the model and an example lesson plan from thermodynamics is shown in the model for any interested researcher who wanted to apply it and replicate the study. As shown in the literature review, the model can only make some contribution to the problem of knowledge transfer and in that it is better than the cognitive perspective and the socio-cultural perspective when taken separately.

4.7 The Proposed Holistic "Spiral Cognitive-Sociocultural Model of Conceptual Change"

There are a number of conceptual change models in science education. The classical conceptual change model (OMCC), the CRKM, the CAMCC and Murphy's model of knowledge and belief change are the prominent ones. In the proposed SCSMCC, the changes in motivation, attitude, perceptions about socio-cultural factors in CAPs strategies and learner study skills as well as conceptual change and knowledge transfer are considered. The SCSMCC is developed to serve as a conceptual and theoretical frame work of the study. This research tried to test the model empirically on two different occasions, to see if it consistently upholds that the model is really a valid one. Such repeated testing allowed me to check for knowledge transfer in addition to conceptual change. The SCSMCC is shown in Figure 1.1 of Chapter One.



Phase 1 of SCSMCC as integrated model (Engaging the Door Keepers-Motivation, Affection, Socio-cultural Contextual Factors): Teacher introduces the topic of the lesson while at the same time motivating and arousing their curiosity and interest in the topic. The RPC strategy used was based on my SCSMCC as holistic model of conceptual change. In this strategy the teacher starts the lesson by motivating and nurturing interest in the particular topic. For example, by telling a history of the particular scientist who contributed to the topic under study, some self-efficacy stories from the teacher or a capable peer etc. This should be done in a short and precise manner for the purpose of not wasting class time. The students should use initial active listening to grasp the task of the day and the teacher should ascertain that s/he has full control over the class. Teacher writes the two categories of valid and invalid conceptions side by side on the board and asks students to decide through argument, evidence and justification as to which category they think is the scientifically correct and valid conception (5 minutes). The word "misconception" or invalid conception "refers to: (1) students' mistaken answers to a particular situation, (2) students' ideas which cause mistaken answers about a particular situation, and (3) students' beliefs about how the world works different than that of the scientists" (Dykstra, Boyle and Monarch, 1992). If a student holds misconceptions, these misconceptions interfere with subsequent learning. For this lesson the categories presented were:

Category one

1. Heat has a property of matter or substance
2. Like heat, temperature is a property of the Material from which a body is made

3. If material A is in thermal equilibrium with Material C and material B is also in equilibrium then A and B are not in equilibrium

Category two

1. Heat is a flow of energy between different substances

2. Temperature is measured as a measure of an average kinetic energy of molecules and it is not an intrinsic property of a Substance

3. If material A is in thermal equilibrium with Material C and material B is also in equilibrium With C, then A and B are in equilibrium

The creation of categories is dictated by the RPC method which requires teacher's provision of a learning material on which learners take position after critically analyzing the material. In this lesson plan the incorrect category is category one.

Phase 2 of SCSMCC as integrated model (Initial Personal Thinking): Allow students to think individually for 3 minutes. They organize their thinking about their background knowledge associated with the topic and identify points of difficulty. Background/prior knowledge when organized and patterned, it will help in knowledge restructuring during, say, classroom discussion. That is what I demanded in this phase of SCSMCC as integrated model of conceptual change.

And take position individually as to which category they think is correct. The Initial Personal Thinking (IPT) phase is actually an exploratory personal discovery phase. Involving students in discussions without some personal thinking results in wastage of time. Students have to learn to think before they actually speak their minds. This should be a good practice well into the rest of their life. Formal reasoning and pre-existing knowledge play an important role in the development of students' conceptions.

Phase 3 of SCSMCC as integrated model (Small Group Discussion): Teacher prompts the students to share ideas and discuss with pre-planned nearest neighbor discussion groups in the process of restructuring their conceptions and come to a group consensus and select a spokesperson for their position's presentation (5 minutes).

Phase 4 of SCSMCC as integrated model (Whole Class Discussion): Each group participates via their spokesperson in whole class discussion and report their position, doubts, and conceptions supported by evidence, reasoning and justification in the process of restructuring their conceptions. The teacher facilitates the process of whole class discussion, clarifies on doubts and drives the learners towards whole

class consensus (7 minutes) as to which category is correct and why it is so. In the discussions, conceptual restructuring is expected to happen.

Phase 5 of SCSMCC as integrated model (Individual Critical Reflection): Students individually look back and critically reflect on and evaluate all what has been discussed, thought, what went wrong, and how it was corrected and any lessons to be drawn from this learning experience. The teacher provides, in the mean time, notes on correct scientific conceptions and explains why they differ from our intuitive every day conceptions of thermodynamic phenomena (10 minutes). This individual reflection phase puts conceptual restructuring on a sound basis.

Phase 6 of SCSMCC as integrated model (Deep Understanding): demonstration of deep understanding by solving problems which resemble real life situations. Application of his/her knowledge in solving problems demonstrates his/her deep understanding of the topic or learning task (10 minutes). This phase reveals whether conceptual change has really occurred. If the change did not occur in the classroom or initial cycle, then the next cycles should be tried by way of tutorials or home work/ assignment/ project or a group study under the guidance of capable peer or adult-expert, and so on. The spiral in the model bridges individual and social formation of concepts in a continuous manner and shows that learning is a life-long process. A type of curriculum that emphasizes the use of knowledge in the context of recall as an end in itself instead of a means for understanding, analysis, synthesis, reasoning, acting and being, ultimately produces people who have inflated self-images but who actually are incapable of adapting to or changing their environment (Amare, 2009:429).

The six phases of the SCSMCC as comprehensive model comprise one cycle of the spiral. If the learner did not achieve deep understanding in the initial cycle s/he can continue outside the classroom by initiating similar cycles.

4.8 The Critical-Analytic Pedagogies (CAPs) Accompanying the SCSMCC as Integrated Model

When learner's personal theories are challenged, they struggle to retain those theories. This is a difficulty but Murphy (2007) asserts that classroom instruction may be oriented to capitalize upon student's passion for their perceptions. This reorientation may be done through a class of pedagogical approaches called Critical Analytic Pedagogies (CAPs) (Chinn et al., 2001; Wade et al., 1994). CAP approaches give prominence to enquiring/questioning (interrogation or querying) topics in search for underlying arguments, assumptions, or world views (Mason, 2001 and Wilkinson et al., 2003). According to these authors, to merit the label 'Critical-Analytic', a pedagogical approach should have the following characteristics:

- *Espouses a goal of helping students make their topic-relevant beliefs and knowledge explicit,*
- *Accept learning as a change in students' beliefs and knowledge,*
- *Acknowledges and values the percepts (feelings) and concepts (ideas) that learners bring to the classroom environment,*
- *Recognizes the power of messages in shaping understanding,*
- *Holds that there is no singular view or understanding relative to complex concepts, and that these competing views are worthy of exploration,*
- *Emphasizes personal and scientific evidence as sources of justification,*
- *Assumes that deep-seated changes in students' understandings come from reaching into the social/cultural, motivational, as well as cognitive realms, and*
- *Values the power of public verifiability and discourse to test whether deep understanding and transfer of learning to real life contexts have been achieved.*

Within the educational literature there are several pedagogical approaches that manifest the aforementioned characteristics. Subsequently, I describe two cases of Critical-Analytic Pedagogies (CAPs): (1) Persuasive Pedagogy (PP) and; (2) Collaborative Reasoning (CR). To support the SCSMCC, I integrate the PP and the CR into one, to use their synergetic effect and labeled it as: Reasoned Persuasive Collaboration (RPC). The RPC is a new CAP to be used in my school-based classroom research to draw empirical evidence for my proposed SCSMCC as holistic model. PP and CR are already empirically tested, and evidence shows that they are effective in conceptual change instruction and research (Mason, 2006).

4.8.1 Persuasive Pedagogy

Persuasive Pedagogy conceptualizes negotiations of knowledge by teachers and students, using their experiences, reasons, perceptions, and potentially viable justifications (Murphy, 2001). It also shows the strength of argument and discourse in the process of conceptual change and belief change. According to Buehl and associates (2005) and Edwards and associates (2005), PP demands critical and analytical evaluation of prior beliefs and knowledge through the use of reason, evidence, and justification. This approach requires that teachers provide materials on which students are asked to take position, and argue to justify that position in the process of instruction. The teacher acts like a change agent by assisting the

learners make their beliefs and knowledge explicit and, therefore, challenge students' perceptions and misconceptions (Murphy, 2001). Empirical evidence suggests increase in learners' beliefs and knowledge (Alexander et al., 2002). Stevens and Fives (2005) found that the use of two-sided refutational texts served as an important impetus for learners positions. That is why I selected a two category lesson plan for each of the 10 lessons of Physical Thermodynamics and each of the 12 lessons of Chemical Thermodynamics. The two categories represent: (1) scientifically accepted category, and (2) commonly misconceived category based on research conducted in Thermodynamics.

4.8.2 Collaborative Reasoning

In order to develop learners' critical reading and thinking of a learning task/message, Collaborative Reasoning (CR) uses discussion as part of instruction. CR is based on reasoned argumentation as a model of critical thinking (Anderson et al., 1998; Chinn et al., 2001), and uses reasoned discourse on learning task/message as a method for taking position on alternative perspectives. The discussion in CR uses conversation between students which draws on background/existing knowledge, personal experience and text book for interpretive scaffolding. Questioning, using central points, will be intentionally used in CR, to evoke varying points of view by the teacher. Learners' take a position on learning task and the teacher encourages them to generate reasons which support their position. Empirical evidence supported that CR resulted in knowledge and belief change than recitation techniques (Chinn et al., 2001). The scientific understandings of the CR group in experimental research who involved in CR discussions showed higher gains as well (Mason, 2001).

4.8.3 Reasoned Persuasive Collaboration

Students' persuasive arguments on a learning task are combined with their reasoned collaborative discussions in the Critical-Analysis of a learning task. Persuasion bridges individual reasoning with group/social collaboration. Students learn how to critically think and evaluate learning materials. This integrates learners' socio-cultural understanding with more cognitively oriented abstract science concepts. Students are required to take a stand about a learning topic when teacher provides them with alternative view points or concepts on learning message. In the discussion they entertain alternative positions or view points until they come to a consensus. The discussion will be fruitful, if each individual student starts by critically thinking about the learning task. If we directly starting the discussions with the group without some prior thought it results in wastage of time and lack of depth of ideas to be shared. Both at the beginning and somewhat near the end of the class the individual learner needs to critically analyze the concepts of the topic. And reflection on learning task follows group and whole class discussions which provides each learner the opportunity to change his/her current conceptions by those accepted in the scientific community. As shown in the SCSMCC as holistic model, the process of learning goes on

spirally in the direction of the learning axis which evolves in the course of time, including learning outside the classroom and to the rest of student's life.

Traditional methods, in this research, are operationally defined as those reported by instructors to make little or no use of CAP approaches, relying primarily on passive-student lectures, and understanding of which is measured by algorithmic/procedural problem exams. Reasoned Persuasive Collaboration(RPC) is operationally defined as a classroom teaching strategy that use in-depth critical analysis of learning content using reason, evidence, justification and argumentation and understanding of which is measured by both conceptual and procedural problem exams.

4.9 Conclusions

Posner and his associates (1982) developed the Orthodox /classical Model of Conceptual Change (OMCC) which emphasizes knowledge change only. This model considered a child like a scientist. Conceptual change was compared with Kuhn's (1962) theory change and conceptual growth as developmental process of Piaget (1929). This model was named as a "cold" model of conceptual change by Pintrich and his associates (1993), since it did not take into account motivational, affective, and socio-cultural contextual factors except the cognitive/rational factors. Dole and Sinatra (1998), based on suggestions put forward by Pintrich and his associates (1993), came up with a model which takes into account motivational factors. This model, called "Cognitive Reconstruction of Knowledge Model (CRKM)", was taken as "warm" model of conceptual change. Dole & Sinatra (1998) raised the "temperature" of their model by including motivational factors in addition to cognitive factors. However, they considered only change in knowledge and changes in motivational factors have not been taken into account. Gregoire (2003) came up with another model of conceptual change which she named as "Cognitive-Affective Model of Conceptual Change (CAMCC)". She added to cognitive factors, motivational and affective factors and therefore claimed to have fulfilled the vision set out in Pintrich and his associates' (1993) article. Because of the inclusion of affective factors, over CRKM, she claimed to have developed a "hot" model of conceptual change, raising the temperature of her conceptual change model one step further compared to Dole & Sinatra (1998) "warm" model. Murphy (2007) came up with a model of knowledge and belief change for conceptual change. Her model not only takes beliefs as facilitators of conceptual change, but requires that these factors themselves change in addition to conceptual change. Her model was a modification and further elaboration of Carey's (1985) cognitive developmental model of conceptual change which has three steps: accretion, weak restructuring, and radical/strong restructuring. Carey's (1985) model of conceptual change is simply an elaboration of Piaget's (1929): assimilation, accommodation, and equilibration and is a "cold" model of conceptual change since it addresses cognitive factors only.

In my proposed SCSMCC as holistic model, the changes in motivation, attitude, perceptions about socio-cultural factors in Critical Analytic Pedagogies strategies and learner study skills as well as conceptual change and knowledge transfer are considered. Thus, I consider SCSMCC as integrated model as a "hot" model of conceptual change. CRKM added motivational factors but did not require their change and CAMCC added motivational and affective factors but did not require their change. Murphy's (2007) model of conceptual change required change in belief in addition to that of conceptual change. The SCSMCC as holistic model added motivational, affective and socio-cultural contextual factors and required their change in addition to conceptual change. Critical Analytic Pedagogies or the RPC method I used in my SCSMCC as integrated model incorporates both logical thinking and experience as a means of knowledge generation and hence conceptual change. The spiral model is considered as a superior model of knowledge acquisition. In accordance with Kant, knowledge is the result of logical thinking of rationalism and sensory experience of empiricism that work together in a spiral fashion. The spiral evolving around the central axis of the conical helix bridges the cognitive and socio-cultural sides of learning theories. In addition to epistemological differences, there are ontological differences between the two perspectives. The cognitive perspective considers the repository of knowledge inside human mind where as the socio-cultural perspective considers the repository of knowledge in the society which is external to the mind. The cognitive perspective uses the methodology of pure reasoning and argumentation. The socio-cultural perspective uses experience or direct observation of reality as a methodology of knowledge generation. Ontologically, the SCSMCC as integrated model considers repository of knowledge as a process that is spirally in transit between the individual and society. Epistemologically, SCSMCC considers knowledge generation as a synergy of rationalism and empiricism. Empirical knowledge generation is here related to experience generated as a result of social interaction. Methodologically, SCSMCC can generate knowledge as a series of alternative interplays between the individual cognitive reasoning, argumentation and justification as well as reflection and socio-cultural persuasion and collaboration in which conceptual restructuring and deep understanding is expected to happen. Therefore, the SCSMCC as comprehensive model conceptualizes this relational character of cognitive and socio-cultural perspectives there by developing a unified model of knowledge acquisition and conceptual change.

CHAPTER FIVE: CONCEPTUAL RESTRUCTURING IN THERMODYNAMICS

5.1 Introduction

In this chapter I will look at how students restructure and change their concepts of thermodynamics. The sources of invalid student conceptions of thermodynamic phenomena are identified and how these invalid or misconceptions are overcome through appropriate conceptual change strategies are discussed. The relationships between conceptual knowledge and procedural knowledge are also discussed. Which of the two knowledge types should come first and how they should be connected and balanced in this sequence? What is students' performance in conceptual and procedural knowledge? These are questions which are answered based on empirical findings from the reviewed literature.

5.2 Identifying and Overcoming of Student Misconceptions in Physical Thermodynamics

In the following, I will try to discuss the process of conceptual restructuring in the domain of thermodynamics. The process involves identifying student misconceptions and overcoming the identified misconceptions.

5.2.1 Identifying Student Misconceptions in Physical Thermodynamics

Students possess a wide variety of misconceptions in physical thermodynamics. There are numerous misconceptions about temperature, heat, internal energy, work, entropy, and free energies. Everyday experience and lay culture concepts act as a barrier to overcome or repair these misconceptions. As an example, if a wooden spoon feels warmer than a metal spoon, does that mean it is at a higher temperature? This example illustrates how everyday experience helps to inform our conceptual (mis)understanding of science. Traditional teaching methods fail to yield conceptual change. There are nearly 7700 reported studies of student misconceptions in science education literature (Duit, 2006). Out of these nearly 600 of them are in the complex field of thermodynamics. Students retain a significant number of robust misconceptions even after learning a heat and thermodynamics unit or course (Miller et al., 2006). In this last study, over 40% of students consistently cannot distinguish between the rate and amount of heat transfer between two bodies at different temperatures and approximately 50% cannot distinguish between the quantity and quality of energy as described by the second law of thermodynamics. Nearly 30% cannot logically distinguish between temperature and energy (Self et al., 2008).

Two challenges must be met to promote deep conceptual understanding in the face of misconceptions: (1) identify prevalent and robust student misconceptions. A list of important but commonly misunderstood concepts in physical thermodynamics was developed by Streveler and associates (2003) and they also

developed concept inventories that can be used to measure the effectiveness of different pedagogical strategies in overcoming misconceptions. (2) Develop a strategy to overcome these misconceptions. The nearly 600 reported studies on thermodynamics focus on aggregate on the following five conceptual themes (Carlton, 2000): (1) Heat and temperature are equivalent. (2) Temperature determines how "cool" or "warm" a body feels. (3) Heat is a substance transferred between bodies. (4) Addition of energy as heat always increases the temperature in a body. (5) Temperature should change in a phase transition since energy is being added or removed.

Temperature and heat are viewed as being equivalent by significant number of students at all grade levels (Arnold & Millar, 1996; Erickson, 1980). Many also consider that temperature is the only variable required to quantify heat energy with no regard to physical state of substance or thermal properties. When asked if 100ml or 40ml of liquid in beakers would lose more energy as they each cooled to room temperature, a common response was that both beakers lose the same amount of energy because the temperature change is the same (Krajcik, 1991). Few students respond that the larger quantity of liquid would lose more energy because it has a greater mass and therefore, had more internal energy stored at the beginning of the experiments. Similarly, gases and liquids at the same temperature are often assumed to possess the same amount of thermal energy.

Lewis and Linn (2003) report findings that suggest children and adults both reply upon intuitive concepts about the temperature of different substances based on how the materials feel. When asked about the temperature of a metal spoon and wooden spoon, both of which were placed in a 65°C oven for 2 hours; only about 20% of the respondents said the temperature of both spoons was 65°C. About 43% stated that the metal spoon was at a higher temperature because metal absorbs heat better than wood or that the metal spoon would feel hotter to the touch. Traditional instruction is most of the time ineffective in changing these alternative conceptions as they are resistant to change and they are persistent (Eryilmooz, 2002). Heat and temperature concepts are very abstract (Harrison et al., 1999) and difficult subjects not only for students but also for scientists and adults (Lewis & Linn, 2003).

Alternative conceptions in thermodynamics usually arise from substance-based conceptions (Harrison et al., 1999). Students thought that heat is a substance, very similar to caloric theory of heat held by scientists in 18th century (Brush, 1976). Most students, as well as adults, could not differentiate the terms "heat" and "temperature" and they use them interchangeably (Harrison, 1996; Jara-Gverro, 1993; Kesidou & Duit, 1993). Students encountered difficulty in accepting that different objects are at the same temperature when left in same environment for a long time (Thomaz et al., 1995). The temperature of an

object is seen as a characteristic of the material from which the object is made. Many students thought that heating an object or a body always increases temperature of an object (Yeo & Zadnik, 2001). An extensive list of alternative conceptions related to thermodynamics was provided by these last authors. Students may answer questions in a test correctly in formal school settings but these students usually fallback to their alternative conceptions while applying to real world contexts (Kolari & Savander-Ranne, 2000; White, 1992).

Students also confuse the use of macroscopic and microscopic approaches. Students tend to treat heat as a substance residing in a body. They also fail to distinguish between the following two forms of the first law and when to use them:

$$(1) \Delta U = Q - W$$

This formula is usually used in non-calculus, algebra-based syllabus/course. In this case the $W \equiv W_{\text{by system}} = P\Delta V$ (isobaric process only).

$$(2) \Delta U = Q + W$$

This formula is usually used for calculus based course. $W \equiv W_{\text{on system}} = -\int PdV$.

Our Grade 12 physics students are learning from a text book which uses the first law in the previous form and even worse the authors wrote the first law as:

$$\Delta U = \Delta Q + \Delta W$$

Giving the impression that Q and W are state functions while they are process functions. I will return to this point in the documentary analysis section in chapter eight. The chemistry text book is better because the authors wrote the first law as:

$$\Delta U = Q + W$$

But they failed to notice that, as do physics text authors, they are dealing with algebra-based Grade 12 science syllabus for which the correct form of first law is:

$$\Delta U = Q - W$$

Students fail to understand that in problems such as compression of a gas in bicycle pump, if the compression is carried out quickly the process is approximately adiabatic ($Q \approx 0$). In this case if we want to calculate the temperature of the gas after compression, we definitely need the ideal gas law, $PV = nRT$. Learners fail to realize that, this equation alone cannot solve the problem. The first law is needed to determine if the product of these two variables ($P \& V$), and hence T increases, decreases, or remains the same.

Students' concept of work from mechanics also confuses its meaning in thermodynamics. In the last example, Loverude and associates (2002) have shown that 75% of students interviewed stated correctly that the temperature of the gas during compression of bicycle pump would increase. But the pattern

emerged have the following features: (1) failure to consider the concept of work; (2) misapplication of ideal gas concepts. Even though they answered correctly that the temperature increases, but they failed to understand the connection between work and the temperature of the gas. The study found out that there is serious difficulty in understanding both when and how to apply the concept. They also found that students fail to analyze the problems in terms of work and the first law of thermodynamics. Students' difficulties with general principles are often intermingled with difficulties related to a specific system to which the principles are applied. Is it enough to arrive at the conclusion that T of compressed gas increases based on $PV=nRT$ alone? The authors related this to faulty reasoning regarding multi-variable relationships. For example, students keep one of the three variables constant, and think of the remaining two about the way they influence each other, consistent with Rozier and Viennot (1992). The other complication arises if they think in terms of molecules rather than macroscopically, assuming a connection between concentration n and $\epsilon_{\text{average}}$ (average molecular energy) and relate this to T .

The molecules undergo elastic collisions and have no internal energy and no potential energy. The only energy they possess is average kinetic energy. In this model T of the gas is related to average kinetic energy. Students do not consider interactions of a system with the surrounding, while making judgments about Q , W and U . Macroscopic arguments may depend on microscopic ones but those connections are not well-established by students. Students are unable to apply the concept of work in thermodynamics. They do not treat the first law as causal relationship in which change in W can bring about change in U . Students look at first law as a mathematical relation devoid of any physical meaning. There is strong tendency to treat the laws as formulas, not as mathematical models which represent important physical principles. Students have difficulty in discriminating such concepts as heat, work, temperature, and internal energy. They confuse process quantities such as Q and W , with associated state quantities such as T , P and U .

There is a tendency to refer to 'heat' as 'change of heat' and 'work' as 'change of work' which emanates from reckless writings of authors of text books and commercial books. Also use ΔP and P (pressure) interchangeably, to mean one another. Students also fail to recognize that work can change the temperature of the system. Some tried to connect heat with work, in attempting to connect W with ΔT . Some students confuse 'mechanical energy transfer' with 'thermal energy transfer', such confusions created difficulties in applying the first law in a correct manner. The students fail to recognize heat and work as independent means of energy transfer. Such confusion is as a result of ideal gas law, $PV=nRT$, which relates PV to T . They consider PV as work done and T as related to heat. As a result, students also

confuse adiabatic ($Q=0$) process with isothermal process ($\Delta T=0$). Students also confuse change of state with isothermal ($\Delta T=0$) and adiabatic ($Q=0$) processes.

Even though work is a scalar quantity, students fail to recognize that the sign of work has physical significance in terms of the change in internal energy of the system. They consider the signs as a matter of convention. They also confuse signs of work, as may be arising from the coordinate system like in the case of vectors. In such cases they fail to understand the physical meaning of negative work. They also fail to understand that work done on and by a system in a given process has the same absolute value. They also fail to distinguish the two sets of sign conventions when the first law is written as: $\Delta U=Q+W$; or $\Delta U=Q-W$. In $\Delta U=Q-W$ for algebra-based course, if work is done on the system, then $W<0$ (negative) or by the system, then $W>0$ (positive). In calculus-based courses, $\Delta U=Q+W$, uses quite the opposite sign convention is followed, that is, W_{on} is positive and W_{by} is negative. Different authors of text books use either of the two sign conventions, sometimes in a very confusing manner.

The confusion can also be imported from mechanics, where work done on the system is mostly either positive or negative. It depends on the relative orientations of **F (force)** and **S (displacement)**. Students also fail to distinguish the physical situation of free or forced expansion/compression of a gas. There is inconsistency in transferring the concept of work from mechanics to thermodynamics; as their interrelations are not mutually exclusive. Transferring the concept of work from mechanics context to thermodynamics context is always difficult for the students. Students also fail to recognize that work is path dependent, and relate work done on system to net change in volume which is only valid when the process is adiabatic and not otherwise. Sometimes students say work is path independent in thermodynamics, trying to relate to conservative forces of mechanics while it is not. Sometimes they confuse the equity of action and reaction for objects in motion even in mechanics. They do not realize that action is greater than the reaction for objects in motion. Therefore, difficulties in using the concept of work to ideal gas processes were rooted in difficulties acquired from mechanics.

Table 5. 1: A list of valid and invalid conceptions in Physical Thermodynamics

Invalid(alternative) conceptions	Valid(normative) conceptions
a. Heat is a material substance like air or steam.	a. Heat is energy in transition between systems.
b. Temperature is used to measure heat, and heat is hot.	b. Temperature shows the degree of 'hotness' and 'coldness' of a body.
c. There is no difference between heat and temperature.	c. Heat is a flow of energy and temperature is a measure of average kinetic energy of molecules.
d. Under the same conditions, metal is colder than plastic.	d. Under the same conditions, metal has the same temperature as plastic.
e. "Cold" is transferred from a colder object to a warmer object; "heat" and "cold" are transferred at the same time.	e. Heat flows from warmer object to colder object only.
f. Metals get hot quickly because they "attract heat", "suck heat in", or "hold heat well".	f. Metals get hot quickly because they are good conductors of heat.
g. Temperature should change in a phase transition since energy is being added or removed.	g. Temperature should not change in phase transition since energy added or removed is due to structural changes.
h. Addition of energy as heat always increases temperature in a body.	h. Addition of energy as heat does not necessarily increase the temperature in a body.
i. Heat is a form of energy, rather than a process of transferring energy.	i. Heat is a process of transferring energy rather than a form of energy.
j. Work done cannot change the temperature (T) of gas in compression.	j. Work done can change the temperature(T) of gas in compression.
k. Heat and work are dependent means of energy transfer.	k. Heat and work are independent means of Energy transfer.
l. No work is done in isothermal process.	l. Work can be done in isothermal process.
m. No heat is transferred in isobaric process.	m. Heat can be transferred in isobaric process.
n. Work can be done in isochoric process.	n. Work cannot be done in isochoric process.
o. Entropy of a system decreases during change of state from solid to liquid to gas.	o. Entropy of a system increases during change of state from solid to liquid to gas.
p. Entropy of a system decreases when mixing of substances occur.	p. Entropy of a system increases when mixing of substances occur.
q. Entropy of a system decreases when it gains energy.	q. Entropy of a system increases when it gains energy.
r. The amount of internal energy that a substance contains determines how weak the force of attraction is between atoms.	r. The amount of internal energy that a substance contains determines how strong the force of attraction is between atoms.
s. In irreversible process entropy decreases.	s. In irreversible process entropy increases
t. Heat is not an extensive quantity, but an intensive quantity.	t. Heat is not an intensive quantity, but an extensive quantity.
u. As the internal energy in a substance decreases, so does the motion of the atoms increases, usually resulting in an increase in force of attraction and a decrease in volume.	u. As the internal energy in a substance decreases, so does the motion of the atoms, usually resulting in an decrease in force of attraction and a decrease in volume.
v. Objects hold heat differently inside and on surface.	v. Objects hold heat at the same rate both inside and on the surface.
x. Surface characteristics determine feeling of heat.	x. Surface characteristics do not determine feeling of heat.

5.2.2 Overcoming Students Misconceptions in Physical Thermodynamics

Many students complete thermodynamics syllabus/course with many of their misconceptions unchanged (Carlton, 2000; Thomaz et al., 1995). Scientists also have difficulties with heat and temperature concepts (Lewis & Linn, 1994). Although they may make more accurate predictions than students, they have difficulty in explaining everyday phenomena (Lewis & Linn, 2003; Tarsitani & Vicentini, 1996).

Promoting conceptual learning is a challenge and more difficult. How do we overcome the strongly held, long-term misconceptions of students? Clearly traditional instructional strategies do not work and students would still possess misconceptions when they graduate. As a result research continues on fruitful conceptual change strategies. Well-designed curricular materials coupled with such methods as analogical and visualization techniques such as computer simulation can overcome strongly held misconceptions which are resistant to overcome by traditional classroom methods. Many other non-traditional model-based strategies exist which may enable us overcome misconceptions and bring about conceptual change. Some empirical studies conducted to change students alternative conceptions related to physical thermodynamics (Clark, 2006; Mustafa Baser, 2006; Self et al., 2008) basically used constructive and/or conceptual change strategies to promote conceptual understanding. Most of them used cognitive conflict as a key strategy (Laura et al., 2005; Thomaz, 1995; Mustafa Baser, 2006). Ma-Naim et al. (2002) used conceptual change oriented approach to improve teachers' understanding of thermodynamics concepts. They showed that teachers in the conceptual change approach teaching model has greater gains than their control group counterparts.

Clark & Jorde (2004) analyzed the effect of an integrated sensory-model within thermal equilibrium visualizations. They found that students in the experimental tactile group significantly outperformed their control group counterparts on posttests and delayed posttests. As stated above, some studies concluded that cognitive conflict has an important/positive effect on conceptual change. Zohar & Aharon-Kravetsky (2005) reported that students with high academic achievements benefited from the cognitive conflict teaching method. Some researchers dispute, however, the effectiveness of cognitive conflict based teaching methods on conceptual change (Limon, 2001; Hewson et al., 1998) and instruction based on cognitive conflict do not necessarily promote conceptual change. This could be related to Pintrich and associates (1993) criticism that the classical model of conceptual change lack changes in motivational factors.

Self (2008) used two strategies to promote conceptual change. One of this is based on computer simulations depicting both molecular-scale and macroscopic dynamics for diffusion and conductive heat transfer which are used to assist students visualize how random movement at a small scale can result in

observable patterns at larger scales. This method worked extremely-well for conceptual change. And the other method involves model-eliciting activities which have been carefully developed to identify student misconception and also fostered conceptual change. Both computer simulations and model eliciting activities results in knowledge change alone and cannot produce the whole child as they lack changes in motivational factors.

5.3 Identifying and Overcoming Students Misconceptions in Chemical Thermodynamics

In the following, I will try to discuss the process of conceptual restructuring in the domain of chemical thermodynamics. The process involves identifying student misconceptions and overcoming those identified misconceptions in chemical thermodynamics.

5.3.1 Difficulties in Teaching and Learning Chemical Thermodynamics

Marèchal and Bilani (2008) presented main difficulties that research in science education has encountered in teaching and learning chemical thermodynamics. Many difficulties have been observed at all levels in teaching and learning chemical thermodynamics (Goedhart & Kaper, 2002). One such learning difficulty has been the confusion of heat and temperature (Erickson & Tiberghien, 1985). In Marèchal and Bilani (2008) study 25% of students in the age range of 12 to 16 answered that there is no difference between temperature and heat concepts and that this percentage remained constant in the course of teaching.

Boo's (1988) study showed that 85% of grade 12 students has the misconception that chemical reactions need an active external causal agent and has the view that the heat supplied to start the reaction as the driving force of the reactions concerned. The reason for this inversion in the cause/effect relation is because heat is often necessary (for kinetic reasons) to run chemical reaction, and even combustions. This explains learning difficulties in distinguishing exothermic and endothermic reactions (De vos & Verdonk, 1986; Galley, 2004).

Boo and Watson's (1998) study reported 48% of the interviewed sample of Grade 12 students after a year of chemistry instruction did not change their conception that bond breaking releases energy. In another study on the same subject, Boo and Watson (2001) have reported that only 29% of the students in year 13, based on the principle that the bonds made were stronger than the bonds broken, reasoned that the reactions were exothermic. Greenbowe and Meltzer (2003) in their calorimetry study reported that students have difficulty making inference about the heat 'absorbed by' the chemical reaction which is equal in magnitude but opposite in sign to the heat 'absorbed by' the solution. Teichert and Stacy (2002) have shown that students had some trouble with sign conventions in energy exchanges. The teaching of energy as a unifying concept in physics cannot be domain specific and is domain general. In introductory

pre-university course, providing correct meaning of the differences between free energy, Enthalpy and Gibbs free energy is not an easy matter. Similarly, the introduction of the concept of entropy is not an easy matter. Teaching these concepts using algebra-based physics text books is difficult.

The two important types of learning are conceptual learning and procedural learning. Conceptual learning deals with conceptual understanding, such as the distinction of heat and temperature. Problem solving or procedural learning involves the uses of strategies and algorithms. Although the two kinds of learning are not mutually exclusive, it has been shown that high problem solving abilities do not necessarily develop good conceptual learning (Nakhleh and Mitchell, 1993). Precise definitions of heat and energy are required in heat and thermodynamics.

Heat is a flow of energy not energy itself. But in the first law of thermodynamics, when no pressure forces are active, the equation reduces to $\Delta U = Q$. From this equation, a good procedural learner can be convinced that heat is energy and therefore acquire a poor conceptual understanding. To overcome this procedure-induced misconception, Maréchal and Bilani (2008) used the energy chain model borrowed from the American physicist, Feynman's, energy considerations. In this model energy is a quantity that belongs to systems and has properties such as: conservative, storable, transferable. According to the model, energy is stored in energy reservoirs and is transferred by means of: heat (Q), work (W) or rays (R). Therefore, any phenomena involving energy can be represented with a chain. A battery or bulb is one such example. This model of energy has been used by the following researchers (Baker & Lund, 1997; Davi et al., 1996). The conservative property of energy can be expressed as $W=Q+R$ for battery and bulb case.

According to Carson & Watson (1999), students come to the University with a very limited understanding of enthalpy change (ΔH) but have knowledge of PV work. In Hess's law calculations of enthalpy changes, it is often argued that reactions occur because the products have a lower enthalpy than the reactants ($\Delta H < 0$). This leads to difficulties in understanding why endothermic reactions occur spontaneously (Cachapuz & Martins, 1987). Students also have difficulties in identifying exothermic and endothermic reactions. Boo (1998) found that about 1/6 of her sample of A-level students thought that copper reacting with air was an endothermic reaction. Similar results were reported by de Vos and Verdonk (1986) in the case of the burning candle. Students often confused the activation energy with the total enthalpy change of the reaction. The other problem is that of linear causal reasoning, an example of concrete operational thinking. For example, thermodynamics depends on multiple macroscopic parameters such as temperature, pressure, and volume.

Rozier and Viennot (1991) found out that students think that changes in systems occur in a series of sequential steps and, for example, takes as a first step the effects of pressure change, then that of temperature change, and finally that of volume change than dealing with all at the same time. Cachapuz & Martins (1987) reported similar reasoning pattern in 17 year olds. The students explained an endothermic reaction as a two phase process: phase one is in which energy is taken as being absorbed in bond breaking and in the second phase energy is released in bond formation while it all occurs at once.

Dixon and Emery(1965) categorized thermodynamic concepts in order of abstraction as: temperature-level1; energy, work, and heat-level 3; enthalpy(H)- level 5, entropy(S)-level 4 and Gibbs free energy(G)-level 6, etc. Students also treat energy changes as matter not as processes. They often also treat work as energy not as a process of transforming energy. They similarly treat heat as well. The representation of heat in thermodynamic equations using symbol Q reinforces the above mentioned view. Mixing the classical and quantum definitions of internal energy (U) and entropy(S) were reported in text books and curriculum guides which makes the process of concept formation much more difficult. Such inconsistencies are prevalent in many texts and commercial books on thermodynamics. Sometimes while U and S are defined in terms of quantum energy levels, enthalpy (H) and Gibbs free energy (G) are considered using classical physics and yet these two sets of quantities are related by equations like,

$$\Delta H = \Delta U + P\Delta V,$$

Where PV work is given by $W = - \int_{v_1}^{v_2} PdV$

If expert authors of books make such confusing mistakes, how would we expect novice learners to form deeper conceptual understanding while at the same time being misguided by the former? Even the most noted authors make these kinds of notational and definitional errors and inconsistencies which add up to lack of correct concept formation in the field of thermodynamics.

There are mismatches between scientifically accepted concepts and students' conceptions (Pfundt and Duit, 1994; Carmichael et al., 1994); when students' construct their own meanings they are influenced by their existing (often incorrect) conceptions (Osborne and Witt rock, 1985). Thermodynamic concepts are abstract. Dixon and Emery (1965) categorized concepts depending on their level of abstraction. Gibbs free energy is the 6th level, enthalpy is at the 5th level and entropy is at the 4th level. Thermodynamics also involves manipulation of two or more variables simultaneously. Rzier and Viennot (1991) reported that students treat such systems in sequential steps instead of dealing with the effects of changing all the variables at the same time. Such linear causal reasoning is an example of concrete operational thinking; whereas dealing with all the variables at the same time is an example of formal operational thinking.

Boo (1998) reported that students at A-level rarely referred to entropy as the driving force of reactions. Pinto's (1991) study showed that few students used entropy to explain every day processes. Sozbilir (2001) reported that students tried to explain entropy as a measure of disorder of the system. Almost all of the respondents defined entropy using their visual disorder point of view, in some cases indicating chaos, randomness or instability. This author showed that the students considered the term 'disorder' as movement, collision of particles and the extent to which things were 'mixed up'. The author found out that students did not have clear understanding of enthalpy and internal energy (energy of the system) and seemed to confuse the kinetic energy of a system with entropy. According to Sozbilir(2001), no student used microstates to explain disorder.

Another difficulty was to understand the term 'spontaneous'. Few appreciated the thermodynamic meaning of the term and believed that reactions were not spontaneous even when $\Delta G < 0$ in $\Delta G = \Delta H - T\Delta S$. Students did not understand that entropy cannot be related to change of state rather it is related to distribution of energy in microstates. In contrast, Harrison and Treagust (2000) have reported that students find it difficult to replace such concrete analogical models with abstract ones.

Students mistake Enthalpy for a process, while it is a function of state, that is, it is dependent only on the initial and final thermodynamic states of the reacting substances. They also lack clear understanding of the thermodynamic meaning of state which includes not only the physical states of substances(solid, liquid, gas) but also the temperature, pressure, and volume of the substance. In addition, students fail to understand that Hess's law is a consequence of the first law of thermodynamics –the conversion of reactants to products involving the total energy transfer will be path independent. They also fail to recognize that at standard state substances must be pure. Students lack of understandings of PV work, can translate into their lack of understanding of enthalpy as they are related by: $\Delta H = \Delta U + P\Delta V$.

Students had difficulty in distinguishing exothermic and endothermic reactions based on changes in entropy (ΔS), enthalpy (ΔH), and Gibbs free energy (ΔG). The authors of chemical thermodynamics text books or units need to give clear cut sign conventions for changes in entropy, enthalpy and Gibbs free energy so that students can easily determine whether the changes indicate exothermic or endothermic reactions.

Research findings shown in Chapter three indicate that students have difficulty in understanding the first law of thermodynamics and associated concepts. They also had difficulty in understanding the concept of enthalpy even after the two treatments.

Table 5.2: A list of valid and invalid conceptions in 'Chemical Thermodynamics'

Invalid(alternative) conceptions	Valid(normative) conceptions
a. Heat and temperature are equivalent.	a. Heat and temperature are not equivalent.
b. The products of chemical reactions need not have the same mass as the reactants.	b. The products of chemical reactions need to have the same mass as the reactants.
c. Collisions between molecules cause heat.	c. Collisions between molecules cannot cause heat.
d. Freezing and boiling are examples of chemical reactions; a phase change is a kind of chemical reaction.	d. Freezing and boiling are not examples of chemical reactions; a phase change is not a kind of chemical reaction.
e. When reversibility of a chemical reaction is observed, it can be explained as phase changes which occur as the temperature fluctuates.	e. When reversibility of a chemical reaction is observed, it should not be explained as phase changes which occur as the temperature fluctuates.
f. Chemical reactions are reactions which produce irreversible change.	f. Chemical reactions are reactions which do not necessarily produce irreversible change only.
g. Combustion is a change of state of matter.	g. Combustion is not a change of state of matter.
h. Chemical reactions must be driven by external intervention such as heat.	h. Chemical reactions need not necessarily be driven by external intervention such as heat.
i. A candle burning is endothermic, since heat is needed to initiate the reaction.	i. A candle burning is exothermic, since heat is needed to initiate the reaction.
j. Covalent bonds are weaker than ionic bonds, and break first on heating.	j. Covalent bonds are stronger than ionic bonds, and break later on heating.
k. The original substances vanish "completely and forever" in a chemical reaction.	k. The original substances do not vanish "completely and forever" in a chemical reaction.
l. Temperature may affect the shape of molecule.	a l. Temperature does not affect the shape of a molecule.
m. Pressure may affect the shape of a molecule.	m. Pressure does not affect the shape of a molecule.
n. Heat makes molecules to expand.	n. Heat does not make molecules to expand.
o. Heating and cooling does not cause changes in particle motion. The particles come together, settle, sink or condense.	o. Heating and cooling cause changes in particle motion. The particles can condense when cooled and agitated when heated.
p. At absolute zero motion of every part of an object stops.	p. At absolute zero motion of every part of an object never stops.
q. There is no limit on the lowest temperature.	q. There is a limit on lowest temperature.
r. Cold can flow.	r. Cold cannot flow.
s. The temperature of any object is related to its size.	s. The temperature of any object is independent of its size.
t. Temperature will change during melting or boiling.	t. Temperature will not change during phase changes.

"Caloric", is an 18th century concept similar to a current misconception of considering heat as a substance which has no mass" (Halliday and Resnick, 1962, pp. 466.467). Caloric theory explained cases

such as heat conduction or mixing of substances in a calorimeter very well, but the fall of caloric theory is due to its consideration of heat as a substance whose total amount remain constant. The caloric theory did not stand the test of time and experiment because it lacked also internal consistence and coherence in dealing with the nature of heat. Even today some people call heat as "something" which transfers from a body at higher temperature to a body at lower temperature.

5.4 The Interplay of Procedural and Conceptual Understandings in the Learning of Thermodynamics

Conceptual understanding is the understanding of substantive concepts. Substantive concepts are the facts, laws, theories and principles of science. Substantive concepts are also known as declarative concepts. In contrast, procedural understanding is the understanding required in knowing how to do science. It is defined here as the understanding and application of (skills and) concepts of evidence. Concepts of evidence are the concepts associated with procedural understanding (Gott & Duggan, 1995). Procedural understanding is complementary to conceptual understanding. Understanding is the ability to explain and interpret information within a given context. Conceptual understanding depends on facts, while procedural understanding depends on skills. We call application as bridging, that is, use of relevant reasoning pattern in a completely different context. This feature promotes learning transfer from one situation to another. Conceptual knowledge and procedural knowledge are assumed to be distinct and yet related. Much effort has been spent to examine their relationship, particularly which one comes first, and which one is dominant.

Some definitions of conceptual knowledge are: (1) Knowledge that is rich in relationships (www.eric.ed.gov), (2) knowledge of the core concepts and principles and their interrelations constructed internally and connected to already existing ideas (Schneider and Stern, 2005), (3) Knowledge that consists of rich relationships or webs of ideas (Stump, 2002), and (4) conceptual knowledge is the ability to show understanding, interpret, and apply concepts between verbal statements and their equivalent mathematical expressions (Engelbrecht et al., 2007). Generally, conceptual knowledge is expressed by the ability to form connection between concepts or between concepts and procedures. Conceptual knowledge is knowing how or why to apply a concept that is adaptable, adjustable and applicable to other situation.

The teaching of conceptual understanding requires posing problems and reason flexibly. In the solution process, students are expected to make connections to what they already know which allows them to extend their prior procedural knowledge and transfer it to new novel contexts.

Some definitions of procedural knowledge are: (1) Knowledge of rules or procedures for solving Physics problems (www.eric.ed.gov), (2) knowledge of operations and the conditions under which these can be used to reach certain goals (Schneider and Stern, 2005), (3) the skill in carrying out procedures flexibly, and appropriately. It includes, but not limited to algorithms, that is, the step by step routines needed to perform mathematical operations (New York Education Department, 2005 as cited in Bosse and Bhar, 2005), (4) the ability to solve a problem through the manipulation of mathematical skills, such as procedures, rules, formulae, algorithms and symbols used in physics (Engelbrecht et al., 2007). It seems that definitions (4) are acceptable for both conceptual and procedural knowledge. The authors of the last definitions in the above asserted that students strongly hold procedural and rule oriented view of physics and assume that physics questions should be quickly solvable in just a few steps, their goal is just to get one right numerical answer.

Conceptual knowledge involves the ability to interrelate concepts, principles and procedures. A concept is an idea generalized from particular and relevant experiences (Carin & Sund, 1989). Examples of concepts are: heat, temperature, entropy, energy, work, light, sound, current, magnetic poles, etc.

Procedural knowledge involves the ability to solve a problem through the manipulation of mathematical skills in a step by step sequential order and associated with non-verbal execution of procedures. Conceptual knowledge must complement procedural knowledge for complete understanding of the subject. Students should give attention to conceptual knowledge than memorizing steps and procedures to solve a problem. Regarding the order in which they are used in a given lesson, Rittle-Johnson and Siegler (1998) concluded that there is no fixed order in the acquisition of procedures versus concepts. In some cases, skills are acquired first; in other cases concepts are acquired first. However, the right sequence seems to first teach conceptual knowledge and to be followed by teaching procedural knowledge. According to Schneider & Stern (2005), conceptual knowledge was a source of children's procedural knowledge, but not vice versa. Engelbrecht et al. (2007), accepted unusualness of their finding which indicated that students do not perform better in procedural problems than in conceptual problems. The finding shows that lack of conceptual understanding will undermine student's performance in procedural understanding as well.

5.5 Conclusions

In conclusion, students should give attention to conceptual understanding than memorizing steps and procedures to solve a problem and based on their conceptual understanding model convert a real life problem into a mathematical equation whenever possible. Abstraction is an important component of conceptual understanding. Conceptual knowledge and metacognitive knowledge require higher

psychological processes or deeper thinking while factual knowledge and procedural knowledge require lower cognitive skills. And hence, Factual, procedural, and conceptual knowledge should be balanced and appropriately sequenced in any science curriculum. If sequencing and balancing are not possible, a pragmatic way of using these knowledge should be devised based on the specific nature of content and context. Results of this research show that factual and conceptual knowledge should precede procedural knowledge for effective physics and chemistry teaching. Conceptual knowledge is the key knowledge as it can help generate both procedures and facts. We need to organize knowledge around key concepts or 'big ideas' of a discipline than around themes or topics. Learning for understanding enhances knowledge transfer to real world or ill-structured contexts. Conceptual Knowledge can help generate a successful solution for procedural problems. Conceptual knowledge helps identify errors in problem-solving procedures and can also help generate alternative procedures appropriate for the context. Complete understanding of the subject requires understanding both procedural understanding and conceptual understanding. Procedural understanding involves understanding of procedures and understanding of the concepts underlying procedures while conceptual understanding involves understanding of facts and substantive/declarative concepts.

CHAPTER SIX: THE INTEGRATED MODEL OF CONCEPTUAL CHANGE: THE CASE OF PHYSICAL THERMODYNAMICS

6.1 Introduction

The purpose of this chapter is to show how the conceptual change approach enhanced deep understanding of thermodynamics, empowered female students, increased the performance of low achievers, and predicted deep understanding of physical thermodynamics from combinations of motivational, affective, socio-cultural contextual factors, treatment and achievement levels. The results discussed include: the effect of conceptual change approach in fostering deep understanding of grade 12 physical thermodynamics unit, empowering female students using the conceptual change approach in learning grade 12 physical thermodynamics unit, the advantage of conceptual change approach in enhancing the performance of low achievers in grade 12 physical thermodynamics unit and prediction of deep understanding of grade 12 physical thermodynamics unit from a combination of extra rational constructs, treatment and achievement levels. APA style tables on gains and bar graphs on total scores illustrate the results throughout the chapter. The results are quoted as evidence to show superiority of the SCSMCC-based RPC method over the traditional transmission of information method.

6.2 Checking for Assumptions

The Exploratory Data Analysis (EDA) by way of generating numbers from the data instead of generating plots was used. Table 6.1, shows that all of the variables which were measured with five levels have skewness values between -1 and 1 and hence they are normally distributed. We can, thus, assume that they are more or less like scale variables rather than ordinal variables. Therefore, we can use parametric statistics that have the assumption of normality. Some parametric statistics are "robust" or the assumptions of normality can be violated without damaging the validity of the statistic (examples are t-test and ANOVA). Non parametric statistics are used when the assumptions of parametric statistic are violated, they do not require normal distribution of variables or homogeneity/equality of variances.

6.3 The Effect of Conceptual Change Approach in Fostering Deeper Understanding of Grade 12 Physical Thermodynamics Unit

In this section I will compare the effect of conceptual change approach with the traditional transmission of information approach in fostering deeper understanding of Grade 12 physical thermodynamics unit. Pintrich and his associates (1993) brought a broader view of the learner, one in which cognitive and extra rational constructs operate in a dynamically interacting way in the study of knowledge restructuring. They simply wanted to see how extra rational constructs might play a role in fostering knowledge change. They did not envisage how extra rational constructs themselves might change. According to them, motivation, affection and socio-cultural contextual factors are complex constructs that interact in dynamic ways with

cognitive constructs such as background knowledge and metacognition. If extra rational constructs are dynamically interacting with cognitive constructs it is also highly likely that they themselves be affected or changed in the change process. Pintrich and associates (1993) only saw their importance in knowledge change but not how they themselves might change in the process of creating the whole child rather than the cognitive child. They also asserted that it is no longer important to do research on learning as occurring in the cold setting of the laboratory that can only examine the cold or rational constructs of cognitive information processing.

The new view of learning is one that is more contextual, cultural, social, and affective as well as cognitive (Pintrich et al.1993). Epistemological beliefs, interest, domain differences, classroom contexts, social and cultural contexts should be considered in conceptual change learning. Conceptual change is now viewed as a complex and dynamic interaction of affective, motivational and socio-cultural contexts (Pintrich et al., 1993). According to them, much work is needed to explicate this new view and extend the research agenda for conceptual change. This is actually the purpose of this research which tried to come up with the model these authors called upon to be developed by future researchers almost two decades ago. A number of models such as CRKM (1998) and CAMCC (2003) were developed to deal with issues of conceptual change learning since Pintrich and associates land mark article of 1993. The SCSMCC takes the research on conceptual change one step further by requiring extra rational constructs themselves change instead of only facilitating knowledge or cognitive change. This makes SCSMCC a truly "hot" model of conceptual change.

My design is predominantly a non-equivalent group's quasi-experimental design in which two intact classrooms were purposely selected from Bole secondary and preparatory school Grade 12 students. The selected sections were 05 and 06. These two sections were found to be almost similar in their Grade 11 final exam results ability distributions when checked for all sections the teacher who agreed to participate handles. This is done to minimize the non-equivalence of comparison and experimental groups in our purposive selection right from the outset. In my research I, not only, required the involvement of "hot" constructs but also their change. The gain is the difference between the post test/administration and the pre-test/administration of all the five continuous variables used in the study.

In implementing the model I developed six phases of the model. In *Phase 1 of SCSMCC (Engaging the Door Keepers-Motivation, Affection, and socio-cultural contextual factors)*: Teacher introduces the topic of the lesson while at the same time motivating and arousing their curiosity and interest in the topic. The RPC strategy used was based on the SCSMCC. In this strategy the teacher starts the lesson by motivating

and nurturing interest in the particular topic. For example, by telling a history of the particular scientist who contributed to the topic under study, some self-efficacy stories from the teacher or a capable peer, etc. This should be done in a short and precise manner for the purpose of not wasting class time. Students are required to actively listen and the teacher should ascertain that s/he has full control over the class.

Teacher writes the two categories of valid and invalid conceptions side by side on the blackboard and asks students to decide through argument, evidence and justification as to which category they think is the scientifically correct and valid conception (5 minutes). The word "misconception" or invalid conception "refers to: (1) students' mistaken answers to a particular situation, (2) students' ideas which cause mistaken answers about a particular situation, and (3) students' beliefs about how the world works different from that of the scientists" (Dykstra et al., 1992). If a student holds misconceptions, these misconceptions interfere with subsequent learning. Even though we used the door keepers in the introduction, the teacher should continue to engage them throughout the class time. In this way we can see how they are themselves changing in addition to assisting in knowledge restructuring and change.

From phase two (*the initial personal thinking phase*) onwards, students individually organize their background knowledge and attempt to relate to the learning task by giving own explanations and taking positions. This helped them to effectively engage in classroom discussions and finally critically reflect on their learning experiences which in turn helped them to apply their deep knowledge to solve problems. This showed that classroom contextual factors are important in knowledge restructuring.

Table 6.1, compares experimental and comparison groups on key variables used in the study. The independent samples t-test shows that the F-test (Levene test) is significant only for 'learning strategies gain' and for this variable the assumption of homogeneity or equality of variance is violated and the **equal variance not assumed** line should be used for the t-test and related statistic. SPSS adjusts the t, df and significance (Sig.) for this case. Thus, for 'learning strategies gain' variable, the appropriate $t = -0.65$, degrees of freedom (df) = 60.02, and $p = 0.518$. This t is not statistically significant, so we can say that comparison and experimental group students did not have difference in physics learning strategies perception gain. This could be due to lack of knowledge of pedagogical techniques. The term gain refers to the difference between post-administration total scores and pre-administration total scores. Students in the two groups did not have difference in their study skills gain scores as well ($p = 0.211$). This could be due to lack of training in study skills provided by schools. On the other hand, Physics test gain ($p = 0.029$), Physics attitude gain ($p = 0.029$) and Physics motivation gain ($p = 0.032$) are statistically significant because their $p < 0.05$. Gains are significant means extra rational or 'hot' constructs have changed significantly in

addition to facilitating ‘cold’ or rational cognitive construct which resulted in knowledge change. Metaphorically, heat flows always from hot body to cold body and as a result in SCSMCC as integrated model of conceptual change “hot” constructs facilitate knowledge change or conceptual restructuring as “cold” construct and interactively affected by the “cold” construct in turn.

Table 6. 1: Comparing experimental and comparison groups on key variables used in the study ($n_{EG}=40$ and $n_{CG}=40$)

Variable	M	SD	MD	t	df	p	Skewness Statistic
Physics Test Gain			5.18	2.22	78	0.029*	0.22
Experimental Group	10.33	10.00					
Comparison Group	5.15	10.82					
Physics Attitude Gain			8.88	2.23	78	0.029*	0.14
Experimental Group	8.10	19.98					
Comparison Group	-0.78	15.40					
Physics Motivation Gain			7.63	2.18	78	0.032*	-0.27
Experimental Group	8.15	14.89					
Comparison Group	0.53	16.30					
Physics Strategies Gain			2.53	0.65	60.02**	0.518	-0.46
Experimental Group	3.78	11.68					
Comparison Group	1.25	21.60					
Physics Study Skills Gain			8.90	1.26	78	0.211	0.16
Experimental Group	8.25	27.02					
Comparison Group	-0.65	35.46					

*The calculated p value is significant at $\alpha=0.05$

**The t and df were adjusted because variances were not equal

When a statistically significant outcome does not give information about the strength or size of the outcome, Cohen’s (1988) Effect Size (d) is used. Effect size measures the strengths of the relationship between the independent variable and the dependent variable and/or the magnitude of the difference between levels of the independent variable with respect to the dependent variable. The effect sizes are expressed in standard deviation units. Usually effect sizes vary from 0 to ± 1 but can be more than 1. Cohen (1988), provided guidelines for interpreting the size of the “effect” for effect size measurement such as d , based on effect sizes usually reported in studies in the behavioral sciences and education. They are classified large (or larger than typical), which is 0.80, medium (or typical), which is 0.50, and small (or smaller than typical), which is 0.20. If $d \geq 1$ (uncommon) it is much larger than typical. The effect size indicates the strength of the relationship and, thus, the relevant practical significance.

Using the data in Table 6.1, d calculated for: Physics test gain is 0.50; for Physics attitude gain is 0.51; for Physics motivation gain is 0.49; for physics perception of learning strategies is 0.10; and for physics study skills is 0.27. The last two are smaller than typical, whereas, the first three are typical or medium.

Thus for full interpretation of t-tests we need Table 6.1 with means and standard deviations to compute the effect size. Conceptual change is now viewed as a complex and dynamic interaction of affective, motivational and socio-cultural context (Pintrich et al., 1993). This kind of complex and dynamic interaction of individual cognitive factors and socio-cultural factors will not result only in knowledge change but also in changes of motivational, affective and socio-cultural contextual factors. This work is needed to explicate this new view and extend the research agenda for conceptual change. The results show that recognition of affective, situational, and motivational factors in addition to cognitive factors helps in developing the whole child. The exclusion of extra rational factors or "hot" constructs will only lead to the cognitive child. By 'hot' constructs I mean those constructs which are different from cognitive or rational constructs.

The results showed that there are significant differences between the two groups in thermodynamics achievement tests, science attitude, and science motivation. Even though there are no significant differences, the graphs and tables have shown that there are small differences in students' perceptions of learning strategies and in their study skills. Both "cold" and "hot" constructs have significantly changed by the treatment. This shows that the SCSMCC (Spiral Cognitive-Sociocultural Model of Conceptual Change) is really a somewhat more comprehensive model than CRKM (Cognitive Reconstruction of Knowledge Model) and CAMCC (Cognitive-Affective Model of Conceptual Change) models which involve extra rational constructs but which did not require them to change. The authors of CRKM and CAMCC took the "hot" constructs as constant during the instructional process but SCSMCC considers the "hot" constructs as dynamic and responsive to the cognitive and socio-cultural environment of learning functionally unified in a symmetric manner using the spiral as a bridge between them. This experimental fact is also shown using post test/administration total scores and pre test/administration total scores in the following figures 6.1 to 6.5.

The figures are simply alternative ways of visualizing changes in the five continuous variables for each group and discrete factors such as gender used in the study. We should carefully plan learning experiences intended for independent learning and those for group/collaborative learning increasing their level of sophistication each time they are repeated in the spiral cycle. The spiral concept is not only applicable to classroom learning but also in developing a high school curriculum in which concept should be presented with increasing depth and more subtle examples across hierarchy of grades. We know that some concepts are repeated at various grade levels and they should be carefully vertically coordinated, say, from ninth grade to twelfth grade. The SCSMCC has also implications for educational policy development in which the pedagogy of learning should require a more careful and balanced approach

between individual/personal development and societal development. The spiral is everywhere in nature, most of the galaxies in the universe are spiral in shape and spirals are evident on our heads and we can see them when our hairs are cut short. We can cite multitude of examples of development in which the processes evolve in a spiral manner.

Figure 6.1, compares the pre-test and post-test total mean scores of the comparison and experimental groups total scores. Table 6.1 compares the two groups using their mean gain scores. The graphs complement table 6.1 by providing mean total scores of the two groups. The graphs show that there are almost no differences in the mean pre-test scores. This could be due to the ANCOVA used to adjust for initial differences. The initial difference between the two groups is 0.20 on a scale of 54 in physical thermodynamics achievement test. The scale is 54 means that the tests are scored out of maximum interval score of 54. The final difference between the two groups on mean post-test scores is 3.38 on a scale of 54 in physical thermodynamics achievement test, which is significant. Figure 6.1 and the mean gain score comparison using table 6.1 corroborate that there is a significant difference between the two groups regarding physics thermodynamics achievement.

The graph shows that rational factors were almost the same in the pre-test but due to treatment of SCSMCC and RPC method the experimental group outperformed the comparison group in the post-test. *In Phase 6 of SCSMCC as integrated model (Deep Understanding):* demonstration of deep understanding by solving problems which resemble real life situations was shown. Application of his/her knowledge in solving problems demonstrates his/her deep understanding of the topic or learning task (10 minutes). This phase reveals whether conceptual change has really occurred. The results have shown that experimental group students have shown significant gain over their comparison group counter parts. The spiral in the model bridges and balances individual and social formation of concepts in a continuous manner and the deep understanding location is shown along the axis of learning at end of each cycle. This shows that the SCSMCC as holistic model is really a valid model in bringing about conceptual change.

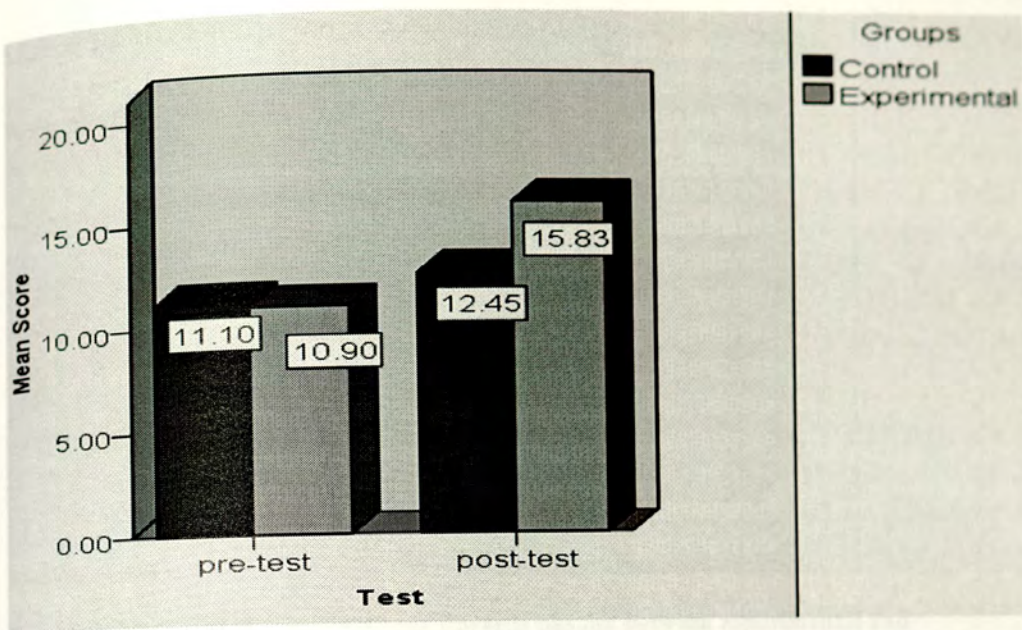


Figure 6. 1: Mean difference in physics achievement between experimental and comparison groups

Figure 6.2, shows the mean difference in total scores of attitude towards physics between experimental and comparison groups. The initial mean difference between the two groups is 0.35 on a scale of 160 in pre-administration of attitude towards physics questionnaire. The scale is 160 means this is the maximum interval score of science attitude scale. The final difference between the two groups on mean post-administration scores of attitude towards physics is 9.22 on a scale of 160, which is a significant difference, both the mean total score comparison using figure 6.2 and the mean gain score comparison using table 6.1 corroborate that there is a significant difference between the two groups regarding attitude towards physics. Figure 6.2 shows that affective/attitudinal factors were almost the same in the pre-administration but due to the treatment of SCSMCC and RPC method used the affective/attitudinal changes are significant for the experimental group but not significant for the comparison group. This means that the treatment positively affected or changed student attitude. Therefore, as shown in phase one of SCSMCC as integrated model of conceptual change, nurturing positive affection of the subject matter throughout the classroom period will result in attitudinal change besides facilitating conceptual change.

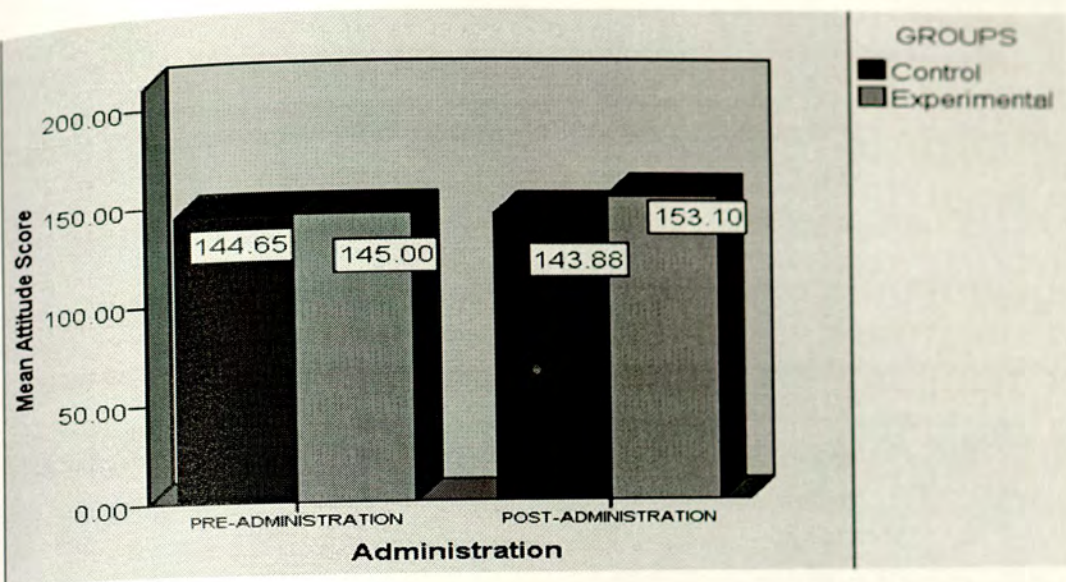


Figure 6. 2: Mean difference in attitude towards physics between experimental and comparison groups

Figure 6.3, shows that the mean difference in physics motivation total scores between experimental and comparison groups'. The initial mean difference between the two groups in pre-administration of science motivation questionnaire is 0.42 on a scale of 120. The scale is 120 means this is the maximum interval score of science motivation scale. The final mean difference between the two groups in post-administration of science motivation questionnaire is 8.05 on a scale of 120, which is significant. Figure 6.3 and the mean gain score comparison using table 6.1 corroborate that there is a significant difference between the two groups regarding motivation for physics learning. Figure 6.3 shows that the key factor of motivation for science teaching is almost the same in pre-administration of the treatment but the motivation has shown significant change for the experimental group but not for the comparison group. The change in student motivation is one of the key achievements of this research as a result of SCSMCC and RPC method which required all cognitive and extra rational factors to be changed in the development of the whole child. This means that the treatment positively motivated or changed student motivation. Therefore, as shown in phase one of SCSMCC as integrated model of conceptual change, nurturing positive motivation of the subject matter throughout the classroom period will result in motivational change besides facilitating conceptual change.

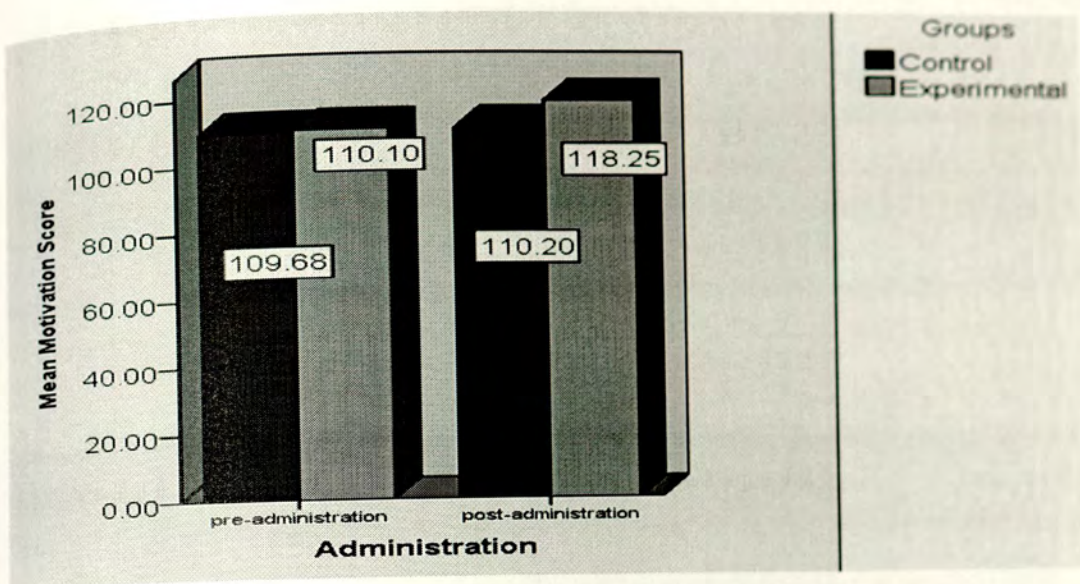


Figure 6. 3: Mean difference in physics motivation between experimental and comparison groups

Figure 6.4, shows that mean difference in physics learning strategies perceptions total scores between experimental and comparison groups. The initial mean difference between the two groups in pre-administration of students' physics learning strategies perceptions is 2.35 on a scale of 80. The scale is 80 means this is the maximum interval score of science learning strategies perceptions scale. The final mean difference between the two groups in post-administration of students' physics learning strategies perceptions is 6.62 on a scale of 80. As the difference between the final and initial differences is 4.27, the change is not significant as shown in the table 6.1 for mean gain scores on perceptions of learning strategies. Student perceptions of learning strategies is constant for the comparison group as shown in figure 6.4, however, even though it is not significant, the change in the experimental group is self-evident from the graph. The SCSMCC and RPC method have somehow impressed the students as there are changes in their perceptions. This means that the treatment positively affected or changed student perceptions or beliefs about learning strategies. Therefore, as shown in phase one of SCSMCC model, nurturing positive perceptions of learning strategies throughout the classroom period will result in perceptual and belief changes besides facilitating conceptual change.

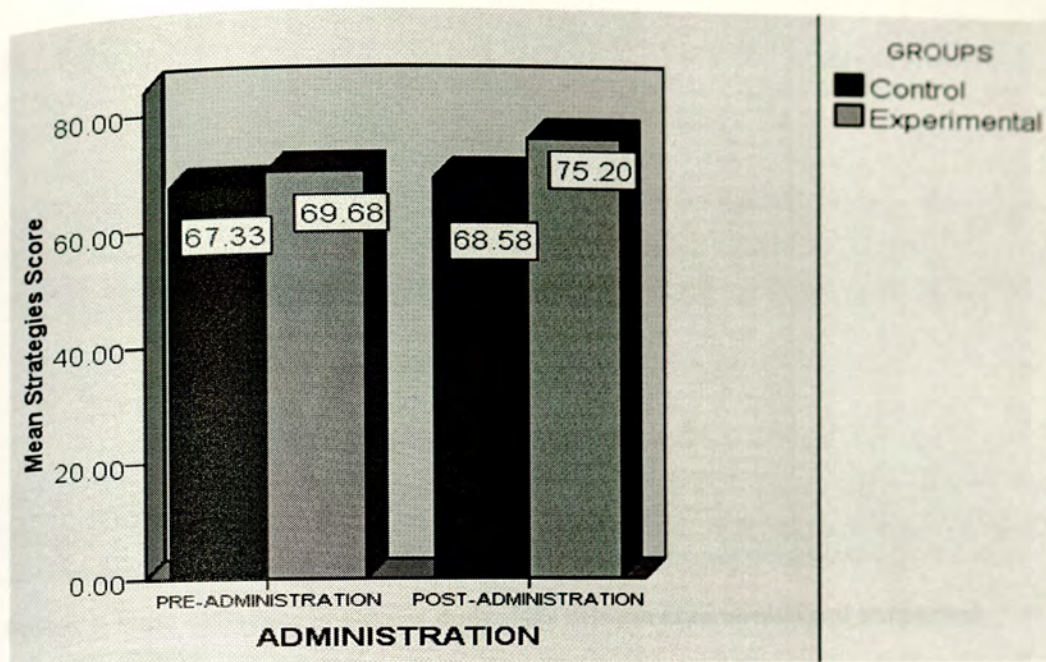


Figure 6. 4: Mean difference in physics learning strategies perceptions between experimental and comparison groups

Figure 6.5, shows mean difference in physics study skills total scores between experimental and comparison groups. The initial mean difference between the two groups in pre-administration of students' study skills is 0.83 on a scale of 204. The scale is 204 means this is the maximum interval score of science study skills scale. The final mean difference between the two groups in post-administration of students' study skills is 9.73 on a scale of 204. On such a large interval scale, the difference of 8.93 between the final and initial administrations is insignificant as shown in table 6.1 for mean gain scores on students' study skills. Student study skills is almost constant for the comparison group as shown in the figure 6.5, however, even though it is not significant the change in the experimental group is self-evident from the graph. As a result of the SCSMCC and RPC method, the students have somehow reconsidered and changed the way they study as there are changes in their study skills. This means that the treatment positively affected or changed student study habits and skills. Therefore, as shown in phase one of SCSMCC model, nurturing systematic and effective study skills of the subject matter throughout the classroom period will result in changes of their study skills besides facilitating conceptual change.

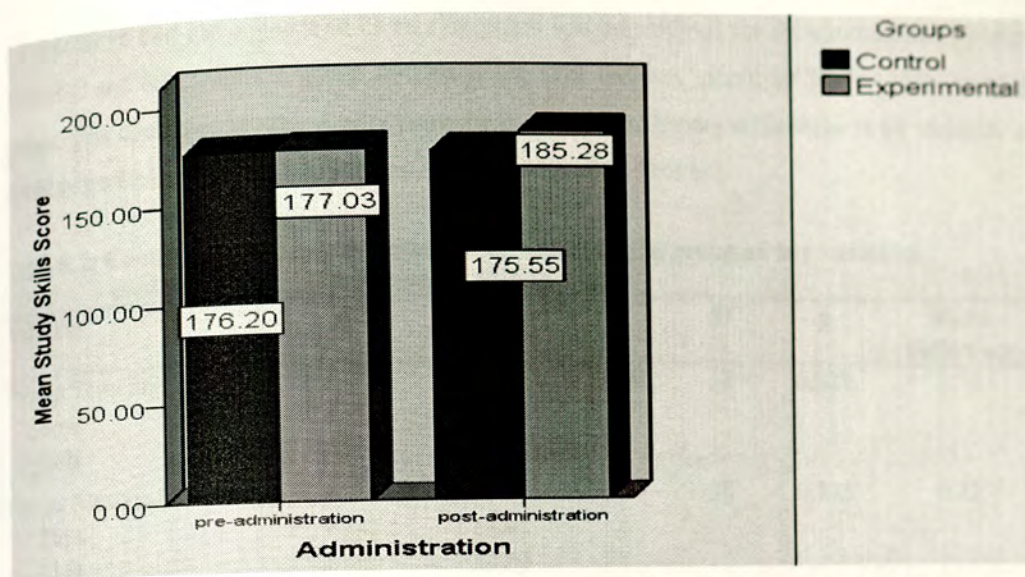


Figure 6. 5: Mean difference in physics study skills between experimental and comparison groups

Therefore, based on results of the above tables and graphs, the overarching null hypothesis of the study, H_0 , is rejected. And also the null sub-hypothesis, H_{01} , is rejected. The results show that the integrated model of conceptual change and its accompanying RPC method is more effective than the traditional transmission of information method and students learn thermodynamics better in SCSMCC-based RPC method than in traditional transmission of information method.

6.4 Empowering Female Students Using the Conceptual Change Approach in Learning Grade 12 Physical Thermodynamics Unit

The purpose of this section is to show how the conceptual change approach empowers female students compared to the traditional transmission of information method. Normality test shows that t-test can be applied to compare means between males and females of comparison and experimental groups. As Table 6.2, shows Levene's test for equality of variances (or F-test) is not significant and hence the 'the equal variance assumed line' can be used for all the variables on which means of male and female of experimental group are compared. The two tailed t-test is not significant for all the variables ($P_i > 0.05$) and hence there is no significant difference between male and female within the experimental group. There is no gender difference in experimental group students regarding the treatment and all other variables on which measurement have been taken. Gender is a factor to be controlled in the research and acts as a noise in the treatment but happily there was no noise of gender origin in the research as the data has shown for the experimental group. Female students were more empowered as shown in table 6.2 of experimental group and male students were better as shown in table 6.3 of comparison group. The results

are conclusive that the conceptual change approach had empowered the female students. As shown by SCSMCC and RPC method group formation not only involves mixed ability but also mixed gender groups. This could be the reason why there are no significant gender differences in all variables used in the study particularly for the experimental group as shown in table 6.2.

Table 6. 2: Comparison of boys and girls of the experimental group on key variables used in the study (n=18 females and 22 males)

Variable	M	SD	t	df	p	Mean Difference
Physics Test Gain			0.99	38	0.329	3.15
Boys	8.91	10.20				
Girls	12.06	9.76				
Physics Attitude Gain			0.04	38	0.973	0.22
Boys	8.00	17.91				
Girls	8.22	22.80				
Physics Motivation Gain			0.75	38	0.458	3.57
Boys	6.55	12.64				
Girls	10.11	17.43				
Physics Strategies Gain			-0.92	38	0.362	-3.43
Boys	5.32	13.13				
Girls	1.89	9.66				
Physics Study Skills Gain			0.85	38	0.401	7.32
Boys	4.96	27.74				
Girls	12.28	26.32				

The mean difference between female and male students of the experimental group students in: physics test gain is 3.15; physics attitude gain is 0.22; physics motivation gain is 3.57; physics learning strategies perceptions gain is -3.43; and physics study skills gain is 7.32 on their respective interval scales. There are no significant ($p > 0.05$) gender differences on all variables. That is exactly what statistical t-test is telling us about the gender difference within the experimental group. Even though the differences are not significant, the female students showed higher measurement values in all variables, except in 'physics learning strategies perceptions' variable than their male counterparts. In physics test gain female students scored 12.06 and male students scored 8.91 on the average. Female students outperformed their male counter parts by 3.15 average points in physics test gain. In physics attitude gain female students scored 8.22 and male students scored 8.00 on the average. Female students have shown more positive affection for physics by 0.22 average points. In physics motivation gain female students scored 10.11 and male students scored 6.55 on the average. Female students were more positively motivated towards physics than male students by 3.56 average points. In physics strategies perception gain male students scored 5.32 and female students scored 1.89 on the average. In this case male students have shown more positive

perception than female students by 3.43 average points. In physics study skills gain female students scored 12.28 and male students scored 4.96 on the average. Female students had a more positive and effective study skills than male students by 7.32 average points. Female students were better in understanding physical thermodynamics, in motivation towards physics and in physics study skills. They were almost the same in attitude towards physics and less than their male counter parts in physics learning strategies perceptions. These show that overall female students were empowered by SCSMCC-based RPC method.

Similar t-test for the comparison group has shown that there are no gender differences in all variables mean gains except for 'physics learning strategies perceptions' variable. In the case of perceptions variable $P=0.01<0.05$ which is significant for the comparison group. Male students outperformed female students of the comparison group in physics test gain as shown in table 6.3 by 3.08 average points. Female students were neither motivated nor had affection for physics as shown in table 6.3. These results corroborate that female students were empowered by the SCSMCC as integrated model of conceptual change and RPC method and the traditional transmission of information method did not empower the female students.

Table 6. 3: Comparison of boys and girls of the comparison group on key variables used in the study (n=24 females and 16 males)

Variable	M	SD	t	df	p	Mean Difference
Physics Test Gain			-0.88	38	0.384 ^a	-3.08
Boys	7.00	12.57				
Girls	3.92	9.57				
Physics Attitude Gain			0.74	38	0.463 ^a	3.71
Boys	-3.00	17.64				
Girls	0.71	13.91				
Physics Motivation Gain			0.34	38	0.735 ^a	1.81
Boys	-0.56	12.50				
Girls	1.25	18.64				
Physics Strategies Gain			2.71	38	0.010 [*]	17.50
Boys	-9.25	23.83				
Girls	8.25	17.12				
Physics Study Skills Gain			-0.69	38	0.494 ^a	-7.96
Boys	4.13	35.99				
Girls	-3.83	35.52				

^{*}The calculated p value is significant at $\alpha=0.05$

^aThere are no significant gender differences on all variables except for physics strategies perception gain

Table 6.4 shows the summary of results depicted in tables 6.2 and 6.3 regarding gender wise understanding of physical thermodynamics unit one of grade 12 physics. The mean difference between experimental and comparison groups male students is 1.91 and that of female students is 8.14 average

gain points. Therefore, we can conclude that female students better performed and empowered by the conceptual change approach in achieving deep understanding of thermodynamics. Both male and female students of the experimental group outperformed their counterparts of the comparison group as shown in Table 6.4. The conceptual change approach is better than the traditional transmission of information approach in fostering deep understanding and in empowering female students.

Table 6. 4: Means, standard deviations, and n for physics test gain as a function of gender and treatment (group)

Group	Males			Females			Total	
	n	M	SD	n	M	SD	M	SD
Experimental	22	8.91	10.19	18	12.06	9.76	10.33	10.00
Comparison	16	7.00	12.56	24	3.92	9.57	5.15	10.82
Total	38	8.11	11.13	42	7.40	10.37	7.74	10.68

The significant F for groups (treatment) means that for the students there is significant difference between females of the two groups. The females of comparison group are less than females of experimental group on mean Physics test gain score ($M=3.92$ vs. 12.06 , respectively). But the males of the two groups did not differ significantly ($M=7.00$ vs. 8.91) on Physics test gain score but still the experimental group students average score is better by 1.91 average points. This shows that females are more argumentative than the males in the treatment that requires reasoning, argumentation, justification and reflection on thermodynamics content.

Figure 6.6, compares the pre-test and post-test mean scores of female and male of comparison and experimental groups. Tables 6.2 and 6.3 have shown that there are no gender differences within experimental groups. Tables 6.2 and 6.3 have shown that there are no gender differences within experimental and comparison groups regarding mean achievement gain scores. The pre-test mean difference between males of comparison and experimental groups is -0.44 on a scale of 54. The post-test mean difference between males of experimental and comparison groups is 2.91 . The pre-test mean difference between females of experimental and comparison groups is -0.07 on a scale of 54. The post test mean difference between females of experimental and comparison groups is 3.82 . In both gender cases, the pre-test mean differences between experimental and comparison groups are not significant but the post-test mean differences are significant which is a comparable result with Table 6.2 in overall differences between the two groups. Flossie-Asekanao Gomile-Chdyaonga's (2003) case study report had shown that boys outperform girls in science and mathematics education and the differential between boys and girls is widest in mathematics and science subjects. According to the report, there are curricular biases and inherited socio-cultural factors which marginalize girls in science subjects. Appropriate

methodologies of teaching which empower girls result in gender balance in science subjects. Results in this research have shown that girls are not inferior in these subjects. And this could be due to application of SCSMCC as integrated model of conceptual change and RPC method which involved not only cognitive factors but also other extra rational factors such as motivation, attitude and socio-cultural contextual factors.

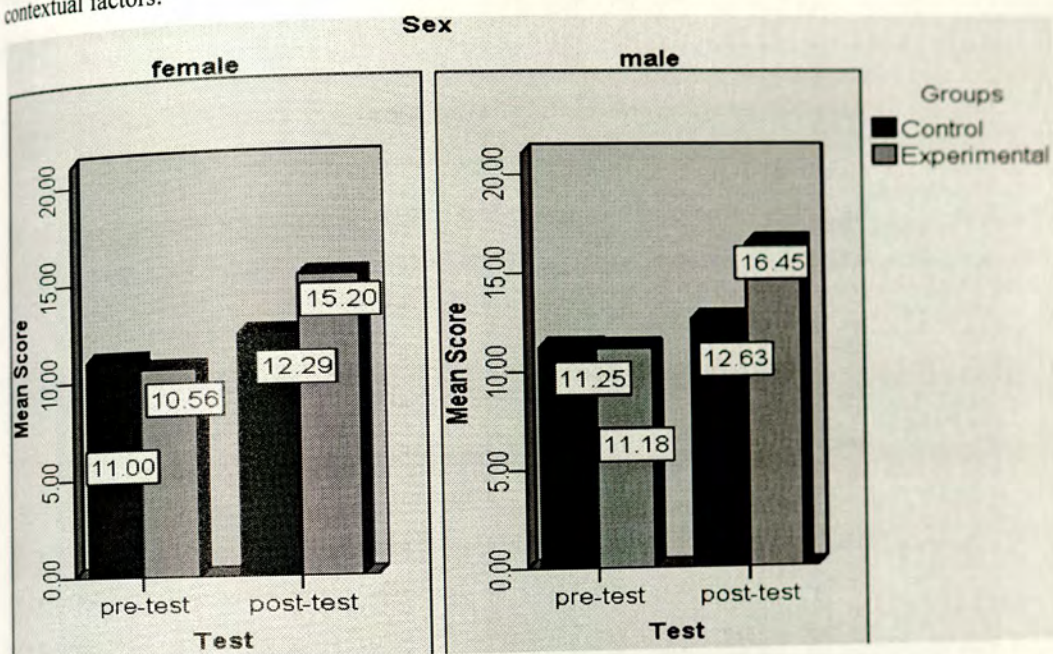


Figure 6.6: Mean difference in physics achievement between male and female of the two groups

Figure 6.7, compares the pre-attitude and post-attitude mean scores of female and male of experimental and comparison groups. Table 6.2 has shown that there are no gender differences within experimental and comparison groups regarding mean attitude gain scores. The pre-attitude mean difference between males of experimental and comparison groups is 0.12 on a scale of 160. The post-attitude mean difference between males of experimental and comparison groups is 8.57 on the same scale. The pre-attitude mean difference between females of experimental and comparison group is 0.49 on a scale of 160. The post-attitude mean difference between females of experimental and comparison groups is 12.30. In both experimental and comparison groups cases involving the two sexes, the pre-attitude test mean difference are not significant but the post-attitude test mean difference are significant, which corroborates the result of Table 6.2 on overall difference between the two groups. The attitudinal change is very clear from Figure 6.7, both females and males of the experimental group have shown significant attitudinal change as a result of application of SCSMCC as comprehensive model of conceptual change and RPC method. They most likely disregard their prior beliefs when their attitudes are positive. Deep processing is more

likely to lead to conceptual change. Negative affect or attitude is related to resistance to new conceptions. Pintrich and associates (1993) also proposed that epistemological beliefs should also be related to knowledge change. Epistemological beliefs are individual's beliefs about the nature of knowledge and the process of knowing. They described these beliefs as "theories" which guides students' thinking. Students who believe that knowledge can be constructed by themselves would promote deep understanding and instigate conceptual change.

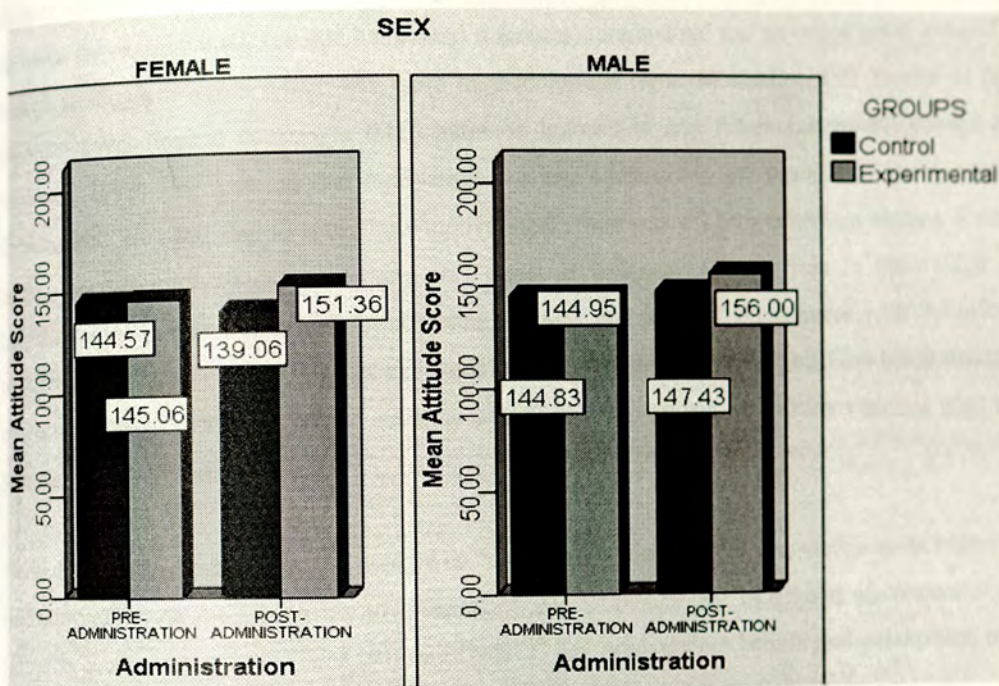


Figure 6. 7: Mean difference in attitude towards physics between male and female of the two groups

Figure 6.8, compares the pre-motivation and post-motivation mean scores of female and male of experimental and comparison groups. Table 6.2 has shown that there are no gender difference within experimental and comparison groups regarding mean physics motivation gain scores. The pre-motivation mean difference between females of experimental and comparison groups is 1.70 on a scale of 120. The post-motivation mean difference between females of experimental and comparison groups is 8.41 on the same scale. The pre-motivation mean difference between males of experimental and comparison groups is 0.92 on a scale of 120. The post-motivation mean difference between males of experimental and comparison groups is 7.50 on same scale. In both cases, the pre-motivation mean differences are not significant but the post motivation mean difference are significant, which corroborates the results of Table 6.2 on overall difference between the two groups.

Motivation is a key factor in conceptual change instruction and I tried to see its change between pre-administration of treatment and post-administration of treatment. Both the female students and male students of the experimental group showed higher motivation than those of comparison groups during post-administration of science motivation questionnaire but there are no gender differences in motivation. Pintrich (1999) also noted that promoting a mastery orientation, awareness of goals and beliefs by students, and teaching self-regulatory strategies should have a concomitant effect on the change process. He called for experimental, reliable behavioral measures, longitudinal and developmental research rather than correlational research which has more methodological rigor. Motivation will be one of the most important psychological constructs that cannot be ignored in any future conceptual change models. Vygotsky (1978) also asserted that motivation is a key construct in the process of learning and child development. We need also to study how motivational constructs trigger conceptual change. Evidence is needed whether motivational constructs play direct or indirect/mediating role in knowledge change. Indirect/mediating role play a role by affecting the type and level of engagement with the information which in turn affect the likelihood of change. The result has shown that SCSMCC as integrated model of conceptual change and RPC method have the effect of raising student motivation which is what we need to occur in science teaching.

"Indeed, learner's epistemic goals, defined as "their motivations towards knowledge as an object" have a mediating effect on the processing of information and ultimately, the likelihood of conceptual change" (Pintrich et al., 1993:p.172). That is how SCSMCC has used student beliefs and perceptions regarding their goals of learning to enhance conceptual change in addition to motivation.

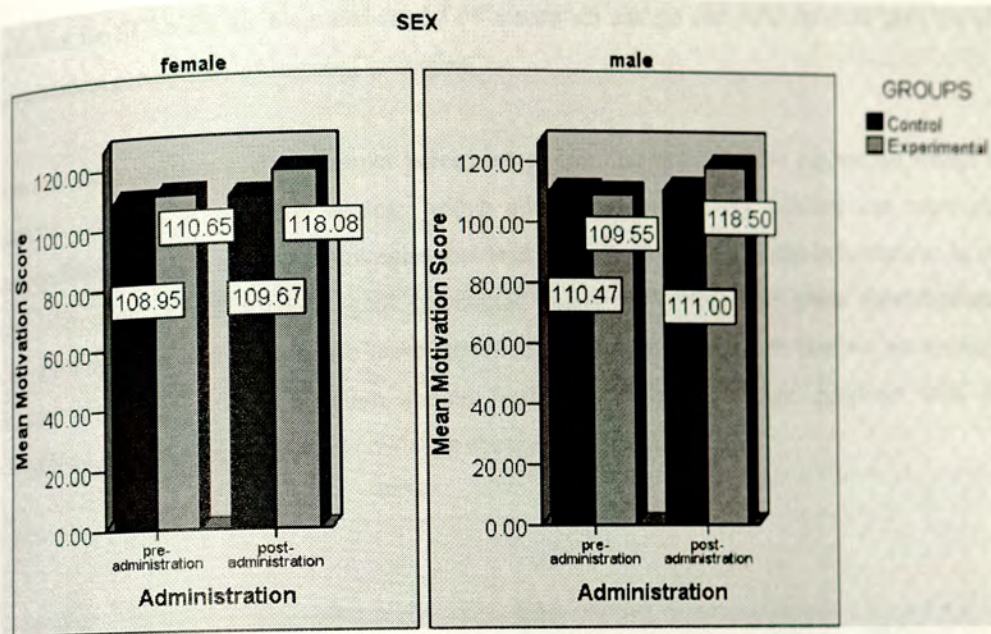


Figure 6.8: Mean difference in physics motivation between male and female of the two groups

Figure 6.9, compares the pre-perception and post-perception mean scores of female and male learning strategies of experimental group and comparison group. Table 6.2 has shown that there are no gender differences within experimental and comparison groups but there is gender difference within comparison group regarding mean physics perception of learning strategies gain scores. The pre-perception of learning strategies mean difference between females of experimental group and comparison group is 5.44 on a scale of 80. The post-perception of learning strategies mean difference between females of experimental and comparison groups is 8.59 on the same scale. The total difference between the pre- and post-perception is 3.15, which shows that the difference between females of the two groups is significant when taken in an overall manner. Females of experimental group had better positive perception of learning strategies than those of the comparison group. The pre-perception of learning strategies mean difference between males of experimental and comparison groups is -0.44 on a scale of 80. The post-perception of learning strategies mean difference between males of experimental and comparison groups is 4.23 on same scale. In each case, the pre-perception mean differences are significant for females of the two groups and the pre-perception mean difference is not significant for males of the two groups. In both cases, the post-perception mean differences are significant, which corroborates the results of Table 6.2 on overall difference between the two groups. Both the females and males of the experimental group showed higher perceptions than those of comparison groups during post-administration of learning strategies questionnaire but there are no gender differences in their perceptions of learning strategies. The result has

shown that the SCSMCC as integrated model of conceptual change and RPC method have the effect of raising student perceptions of learning strategies.

Extra rational constructs such as learner perception of learning strategies are embedded within specific classroom contexts. A teaching strategy which adopt goal of mastery content use more elaborate metacognitive and self-regulatory strategies that lead to deep processing of the information. In contrast, those who adopt a performance goal orientation focus on getting the grade (result-oriented) or outperforming peers and tend to use more superficial strategies, resulting in shallow processing. Thus, adoption of mastery goal orientation should facilitate conceptual change. Students with different achievement goals would approach knowledge change differently.

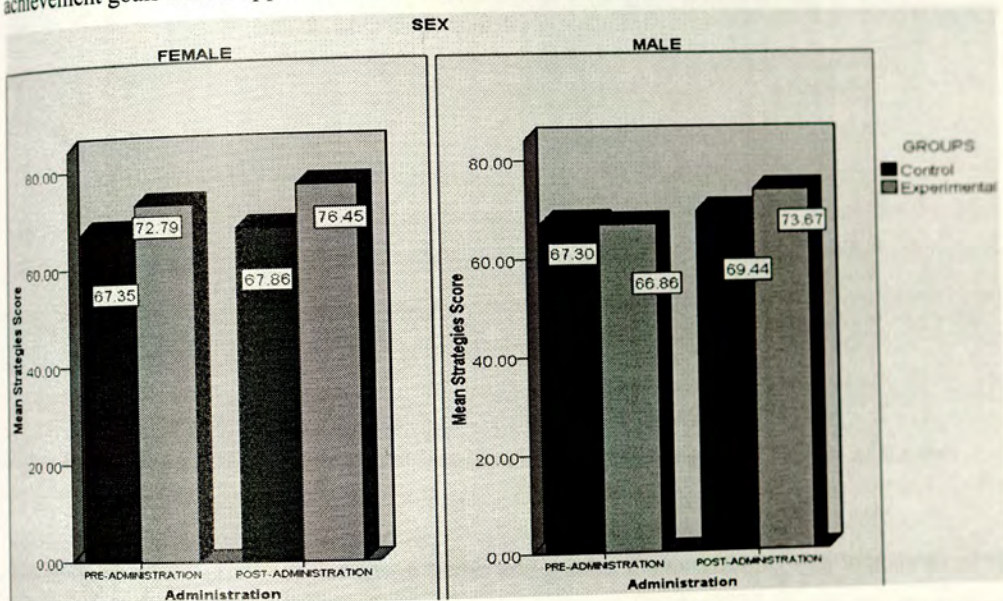


Figure 6. 9: Mean difference in physics learning strategies perceptions between male and female of the two groups

Figure 6.10, compares the pre-study skills and post-study skills mean scores of female and male study skills of experimental group and comparison group. Table 6.2 has shown that there are no gender difference within experimental group and comparison group regarding mean physics study skills gain scores. The pre-study skills mean difference between females of experimental group and comparison group is 0.66 on a scale of 204. The post-study skills mean difference between females of experimental group and comparison group is 16.23 on the same scale. The pre-study skills mean difference between males of experimental group and comparison group is 1.51 on the same scale. The post-study skills mean difference between males of experimental and comparison groups is also 1.51 on same scale, which shows that there is no change in study skills between pre- and post-study skills, while there is a change in

females study skills between experimental and comparison groups. Overall there is no significant difference between the experimental group and comparison group in their study skills, which corroborates the results of Table 6.2 on overall difference between the two groups. This variable was included in the study to see if it significantly affects the outcome of the study but as expected this variable is effectively controlled as a confounding variable but there are gender differences in study skills. The female of experimental group has shown increased study skills as a result of treatment of SCSMCC and RPC method which showed that they are more willing to study together than their male counter parts.

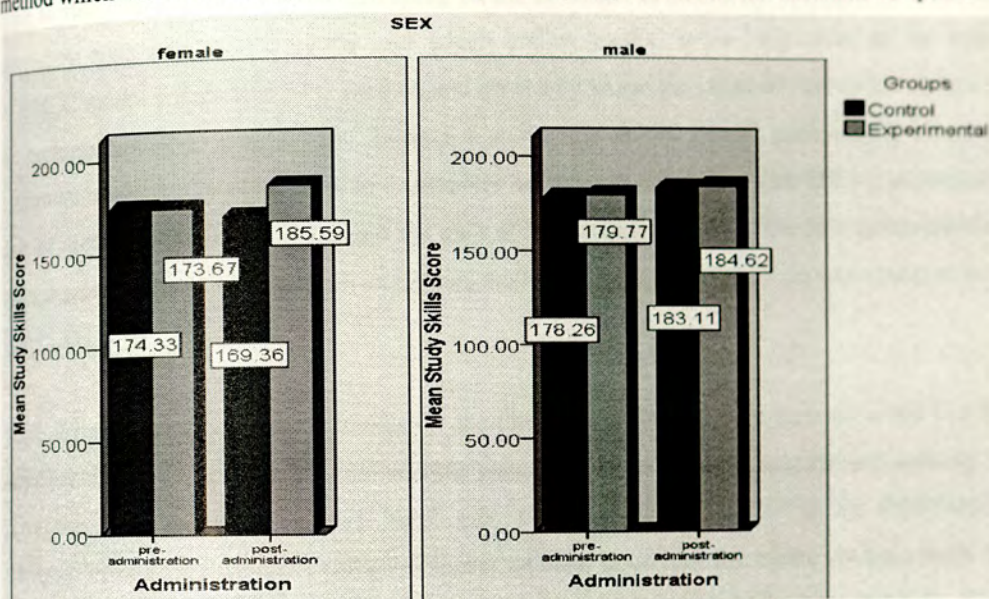


Figure 6.10: Mean difference in physics study skills between male and female of the two groups

Therefore, based on results of the above tables and graphs, the overarching null hypothesis of the study, H_0 , is rejected. And also the null sub-hypothesis, H_{02} , is rejected. In general, the female students of the treatment group outperformed, even though not significant, their male counterparts in understanding grade 12 physical thermodynamics unit. Most of the extrarational constructs were enhanced for female students compared to comparison group female students. Therefore, the SCSMCC as integrated model of conceptual change has definitely empowered female students in understanding physics as a science subject.

6.5 The Advantage of Conceptual Change Approach in Enhancing the Performance of Low Achievers in Grade 12 Physical Thermodynamics Unit

The purpose of this section is to show how the SCSMCC as integrated model of conceptual change and RPC method enhance the performance of low achievers compared to the traditional transmission of information method. The results of medium and high achievers of the treatment group are also used for

comparison. In this case we use one-way ANOVA or single factor analysis of variance because there is only one independent variable or factor. The independent variable/factor has nominal or a few ordered levels. The assumptions of ANOVA are: observations or scores are independent, equal variance on the dependent variable across groups, and the dependent variable is normally distributed for each group. We use one-way ANOVA because we have one independent variable/factor which is the ability levels. We can do several one-way ANOVAs at a time using SPSS or which we call MANOVA. This analysis is done to study the effects of ability grouping on the academic achievement of Grade 12 students of Bole secondary school in Addis Ababa and which ability level(s) is/are responsive to the treatment of SCSMCC model which uses RPC method and especially to see the effect of conceptual change approach on performance of low achievers. Table 6.4 shows the ability groups performance of experimental classroom in physics test gain. The low achievers have shown the highest gain (19.11) as compared to the gain of medium achievers (10.52) and the gain of high achievers (2.00). The low achievers have shown highest gain in other variables such as physics motivation gain (12.67) and physics strategies perceptions gain (5.33).

Table 6.5 provides descriptive statistics for the three ability levels/groups on each of the five dependent variables--Physics test gain, Physics attitude gain, Physics motivation gain, Physics learning strategies perceptions gain and Physics study skills gain taken for the analysis within the experimental group. Although these five dependent variables appear together in each of the tables, we have really computed five separate one-way ANOVAs. In this table, low achievers has the highest mean in: Physics test gain(19.11), Physics motivation gain (12.67), and Physics learning strategies perceptions gain (5.33). In the same table, medium achievers have the highest mean in: Physics attitude gain (12.33) and Physics study skills gain (14.10). The high achievers has almost the lowest gain in all variables, which shows that the order of reception of the new strategy/model was highest in low achievers, average in medium achievers and lowest in high achievers, in the experimental group. No such pattern or even clear pattern is observed in the mean gains of the comparison group in Table 6.5. Even the magnitudes of the gains are small compared to the experimental group as shown in this table. Pintrich and associates (1993) also proposed that high self-efficacy for learning may create confidence in one's ability to engage in change-promoting activities such as argumentation and experimentation. High self-efficacy, however, could translate into confidence in one's current conception, thus creating intolerance for change (Pintrich, 1999).

Research suggests that a tendency to hold on to one's point of view impedes the likelihood of change(Sinatra, Southerland, and Demastes, 2004). This suggests conceptual change pedagogies such as

the SCSMCC as integrated model of conceptual change which uses RPC method should be designed to reduce their resistance to conceptual change. As shown from the data above, resistance to new ideas is low in low achievers, average in medium achievers, and highest in high achievers. This can either be due to correct conceptions they already hold at the beginning of the treatment or corroborates the above cited authors views that the higher the self-efficacy, the higher the resistance to new ideas as far as treatment of 'Physical Thermodynamics' is concerned. However, this is not always true as we can shortly see in chapter seven's "Chemical Thermodynamics' treatment. Probably the background knowledge of 'Physical Thermodynamics' could have affected the way their self-efficacy promoted conceptual change. Background knowledge-well established in psychological literature as a facilitator of learning could have affected or lowered the degree of resistance to new conceptions.

Table 6. 5 :Means and standard deviations comparing the three ability groups of experimental group students

Ability levels	n	Physics Test Gain		Physics Attitude Gain		Physics Motivation Gain		Physics Strategies Gain		Physics Study Skills Gain	
		M	SD	M	SD	M	SD	M	SD	M	SD
Low achievers	9	19.11	8.36	2.44	22.13	12.67	9.87	5.33	17.01	5.22	27.96
Medium achievers	21	10.52	6.87	12.33	17.13	8.38	15.49	2.71	11.56	14.10	25.41
High achievers	10	2.00	10.60	4.30	23.52	3.60	17.24	4.60	5.58	-1.30	29.04
Total	40	10.33	10.00	8.10	19.98	8.15	14.89	3.78	11.68	8.25	27.02

Table 6.6 shows the test of Homogeneity of variables for all the five variables together with the ANOVA table. The Levene test is significant for 'physics perception gains' of experimental group and for 'physics study skills' of the comparison group (0.006), so the variances are significantly different. The degree of freedom for both groups is: 2, 37. The between group differences for 'physics test gain' is the only significant gain ($p < 0.05$) for both the experimental and the comparison groups. For the 'physics perception gain' ($p = 0.005$) of experimental group and for the 'physics study skills' ($p = 0.006$) of comparison group, the assumption of equal variance is violated and we should use for the two cases the similar non-parametric test, the Kruskal-Wallis test, since the overall F is not significant in the ANOVA table of the experimental group and of the comparison group for the respective variables (if the overall F were significant we could use a post hoc test (such as Tukey) designed for situations in which the variances are unequal).

Table 6. 6: One-way analysis of variance summary table for experimental group comparing ability levels on the key variables used in the study

Source	df	SS	MS	F	p
Physics Test Gain					
Between groups	2	1388.65	694.32	10.23	0.000*
Within groups	37	2512.13	67.90		
Total	39	3900.78			
Physics Attitude Gain					
Between groups	2	808.61	404.31	1.01	0.373
Within groups	37	14766.99	399.11		
Total	39	15575.60			
Physics Motivation Gain					
Between groups	2	391.75	195.87	0.88	0.424
Within groups	37	8253.35	223.06		
Total	39	8645.10			
Physics Strategies Gain					
Between groups	2	52.29	26.15	0.18	0.833
Within groups	37	5270.69	142.45		
Total	39	5322.98			
Physics Study Skills Gain					
Between groups	2	1712.04	856.02	1.18	0.317
Within groups	37	26759.47	723.23		
Total	39	28471.50			

* $p < 0.001$

The ANOVA part of the table is the key part because it shows whether the overall F , for these five ANOVA s' were significant or not. Note that the three ability levels differ significantly on 'physics test gain in both the experimental and comparison groups but not on other variables. $F(2, 37) = 10.23$, $p = 0.000$, for physics test gain of the comparison group. The 2, 37 are the degrees of freedom (df) for the between groups "effect" and within groups "error" respectively. However, when we have 3 or more groups we may not know which specific pairs of means are statistically different, unless we do a post hoc or *a priori* comparison test. In the above we have seen that the overall F for ANOVA is significant only for 'physics test gain' of the experimental group and comparison group. We use Tukey HSD (Honestly Significant Differences) test, if the Levene test was not significant or the Games Howell test, if the Levene test was significant. In our case, the Levene test was not significant for both experimental group and comparison group on physics test gains and hence we should use the Tukey post hoc test. We do post hoc tests only if the overall F is significant. The one-way ANOVA table help us in deciding whether to use post hoc multiple comparison tests. If the groups are more than two (or two repeated measures) we use either of the above two tests to determine the sources of the differences.

Table 6. 7: Means and standard deviations comparing the three ability groups of comparison group students

Ability levels	n	Physics Test Gain		Physics Attitude Gain		Physics Motivation Gain		Physics Strategies Gain		Physics Study Skills Gain	
		M	SD	M	SD	M	SD	M	SD	M	SD
Low achievers	12	4.79	11.15	-3.86	16.22	-1.57	13.73	0.86	26.56	-9.14	2.66
Medium achievers	19	3.18	8.68	0.59	14.91	5.06	12.86	-0.71	18.47	3.59	46.77
High achievers	9	- 1.44	9.15	1.44	16.06	-4.78	23.98	5.56	20.42	4.56	17.82
Total	40	5.15	10.82	-0.78	15.40	0.53	16.30	1.25	21.60	-0.65	35.46

If the overall F is significant, which pairs of means are significantly different?

The Kruskal-Wallis test can be used in this case. Mean ranks for 'physics perception gain' of experimental group and for 'physics study skills gain' of comparison group indicate medium 'physics perception gain' and 'physics study skills gain' for the two groups.

The ranks table provides mean ranks for the two dependent variables, 'physics perception of learning strategies gain', of the experimental group and 'physics study skills gain' of the comparison group. The Kruskal-Wallis test will compare the mean ranks for the three ability levels of the two groups. The test statistics table shows that there is an overall difference among the three ability groups which shows that there is no significant ($p=0.875$) difference among the three ability groups of experimental section regarding 'physics perception of learning strategies gain' and among the three ability groups of comparison ($p=0.405$) section regarding 'physics study skills gain' and no *post hoc* tests are required as K-W tests are not statistically significant.

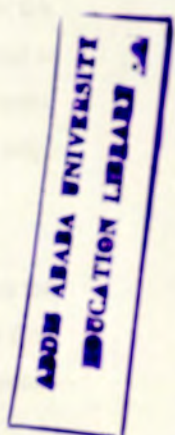


Table 6. 8: One-way analysis of variance summary table for comparison group comparing ability levels on the key variables used in the study

Source	df	SS	MS	F	p
Physics Test Gain	2	1074.05	537.03	5.69	0.007
Between groups	37	3493.05	94.41		
Within groups	39	4567.10			
Total					
Physics Attitude Gain	2	208.92	104.46	0.43	0.655
Between groups	37	9040.05	244.33		
Within groups	39	9248.98			
Total					
Physics Motivation Gain	2	664.05	332.03	1.27	0.294
Between groups	37	9697.93	262.11		
Within groups	39	10361.98			
Total					
Physics Strategies Gain	2	234.03	117.02	0.24	0.787
Between groups	37	17959.47	485.39		
Within groups	39	18193.50			
Total					
Physics Study Skills Gain	2	1559.05	779.52	0.61	0.550
Between groups	37	47490.05	1288.52		
Within groups	39	49049.10			
Total					

The Tukey HSD is a common *post hoc* test to use when variables are equal. This table is most appropriate when the group's n_s are similar. Here they are quite different. The mean difference (i-j) could be shown alongside the significance levels, if the group sizes were similar. We should ignore duplicates in the table. The ANOVA table is repeated here. The second part of the output shows the Tukey HSD test for ability levels. For physics test gain this Tukey table indicates that there is a significant difference between the ability levels of the experimental group. For this same variable, there is significant difference between 'low achievers' and 'medium achievers' and 'low achievers' and 'high achievers' but there is no significant difference between 'medium achievers' and 'high achievers' of the comparison group ($p=0.488$).

Table 6. 9: Post hoc multiple comparisons of physics test gain of the experimental group using Tukey HSD test

(I) Ability Levels	(J) Ability Levels	Mean Difference (I-J)	Standard Error	P	95% Confidence Interval	
					Lower Bound	Upper Bound
Low Achievers	Medium	8.59	3.28	0.033*	0.57	16.60
	Achievers					
	High Achievers	17.11	3.79	0.000*	7.87	26.35
Medium Achievers	Low Achievers	-8.59	3.28	0.033*	-16.60	-0.57
	High Achievers	8.52	3.17	0.028*	0.79	16.25
High Achievers	Low Achievers	-17.11	3.79	0.000*	-26.35	-7.87
	Medium					
	Achievers	-8.52	3.17	0.028*	-16.25	-0.79

*All mean differences are significant at $\alpha=0.05$ level

Post hoc analysis (from Latin *post hoc* means “after this”) in the context of design and analysis of experiments refers to looking at the data-after the experiment has concluded-for patterns that were not specified *a priori*. It is sometimes called *data dredging*, that is, the more one looks into the data, the more likely that something will be found. Post hoc tests are also known as *a posteriori* or *follow up* tests. In this case the three ability levels are unequal in sample size and we should use the harmonic mean instead of the predetermined mean of equal sample size. The mean comparisons from Table 6.6 for the experimental group are statistically significant. The Tukey test requires computation of the so-called studentized range for three or more groups.

Post hoc Tukey HSD tests indicate that the three ability levels differed significantly in their ‘Physics test gain score’ for the experimental group ($p < 0.05$) and similar post hoc Tukey HSD tests indicate the three ability levels differed significantly in their ‘Physics test gain score’ for low achievers and medium achievers, and low and high but not for medium and high achievers of the comparison group.

Table 6. 10: Post hoc multiple comparisons of physics test gain of the comparison group using Tukey HSD test

(I) Ability Levels	(J) Ability Levels	Mean Difference (I-J)	Standard Error	P	95% Confidence Interval	
					Lower Bound	Upper Bound
Low Achievers	Medium Achievers	8.61	3.51	0.048*	0.05	17.17
	High Achievers	13.23	4.15	0.008*	3.09	23.37
Medium Achievers	Low Achievers	-8.61	3.51	0.048*	-17.17	-0.05
	High Achievers	4.62	4.01	0.488	-5.16	14.40
High Achievers	Low Achievers	-13.23	4.15	0.008*	-23.37	-3.09
	Medium Achievers	-4.62	4.01	0.488	-14.40	5.16

*Mean differences are significant at $\alpha = 0.05$ level

The homogeneous subsets table shows an **adjusted Tukey** that is appropriate when group sizes are not similar, as in this case. Note that there is not a statistically significant difference ($p = 1.00$) between ability levels in their ‘Physics test gain’ of the experimental group and similarly there is not a statistically significant difference between the ability levels of the comparison group.

Therefore, a statistically significant difference was found among the three ability levels on ‘Physics test gain’, $F(2, 37) = 10.23$, $p = 0.000$ for the experimental group and $F(2, 37) = 5.69$, $p = 0.007$ for the comparison group. Table 6.5 shows that the mean Physics test gain score of experimental group: for high achievers is 2.00, for medium achievers is 10.52, and for low achievers is 19.11. And the mean Physics

test gain score of comparison: for high achievers is -1.44, for medium achievers is 3.18, and for low achievers is 11.79.

Table 6.11, shows the means and standard deviations for Physics test gain separately for the two groups and the three ability levels. This table shows the general trend in both comparison and experimental groups is that the mean gain on ‘Physics test gain’ decreases as we move from low to medium, and to high achievers. The comparison group trend in gain is LA=11.79, MA=3.18, and HA=-1.44; the experimental group trend in gains is LA=19.11, MA=10.52, and HA=2.00. The gains are lowest for HAs and highest for LAs (low achievers) but the magnitudes are larger for all groups of the experimental students. This can be explained by the fact that students with high self-efficacy are resistant to change their conceptions.

Table 6. 11: Means, standard deviations, and n for physics test gain as a function of treatment (group) and ability levels

Ability Levels	Experimental Group			Comparison Group			Total	
	n	M	SD	n	M	SD	M	SD
Low Achievers	9	19.11	8.36	12	11.79	11.15	14.65	10.60
Medium Achievers	21	10.52	6.87	19	3.18	8.68	7.24	8.47
High Achievers	10	2.00	10.59	9	-1.44	9.15	0.37	9.82
Total	40	10.33	10.00	40	5.15	10.82	7.74	10.68

In general, the degree of enhancement of the performance of all achievement groups is higher for experimental group than for the comparison group. And the degree of enhancement of performance of low achievers is higher within the experimental group ability levels. The gain of low achievers of experimental group students is higher than the gain of low achievers of comparison group by 7.32 average gain points. Therefore, the conceptual change approach has an advantage of enhancing the performance of low achievers compared to the traditional transmission approach.

Therefore, based on results of the above tables, the overarching null hypothesis of the study, H_{01} , is rejected. And also the null sub-hypothesis, H_{03} , is rejected. In general, the low achievers of the treatment group outperformed their comparison group counterparts in understanding grade 12 physical thermodynamics unit. Most of the extrarational constructs were enhanced for low achievers students compared to comparison group low achievers students. Therefore, the SCSMCC as integrated model of conceptual change has definitely enhanced the performance of low achievers in experimental group and understanding of physics as a science subject.

6.6 Prediction of Deep Understanding of Grade 12 Physical Thermodynamics Unit from a Combination of Extra rational Constructs, Treatment and Achievement Levels

Multiple linear regressions use only the participants who have complete data (list wise exclusion) for all the variables in descriptive statistics. The first column of Table 6.12, below, of the correlation matrix shows that for the experimental group, the correlations of the other variables with 'Physics test gain'. Note that except for 'ability levels' enhanced by the treatment ($p=0.000$), the other variables are not significantly correlated with 'Physics test gain'. Also note that 'ability levels' is highly correlated with 'Physics test gain' (-0.60). Motivational constructs are like double-edged sword in that the valence of the construct can have a positive or negative effect on learning outcome. Their impact can be towards adopting or resisting a new idea. The negative correlation showed that the higher the ability level the higher the resistance to conceptual change which shows that the gain for high achievers in physics tests between pre-test and post-test is the lowest as shown in Table 6.5. High self-efficacy, as the power of believing we can, for learning may create confidence in one's ability to engage in change-promoting activities such as argumentation and experimentation. High self-efficacy, however, could also translate into confidence in one's current conception, thus creating intolerance for change (Pintrich, 1999). Research suggests that a tendency to hold on to one's point of view impedes the likelihood of change (Sinatra, Southerland, and Demastes, 2004). The findings of this research corroborate the above mentioned researchers ideas and results. Two predictor variables 'Physics motivation gain ' and 'Physics learning strategies perceptions gain' are positively correlated with each other significantly($p=0.024<0.05$) for which $r=0.32$. This shows that SCSMCC as integrated model of conceptual change and RPC method highly motivated the students such that their learning strategies perceptions are increased as a result. This shows the idea that socio-cultural or classroom contextual factors, such as perceptions about learning strategies, can be used as motivators of science learning.

Pintrich and associates (1993) analyzed the role of extra rational constructs in facilitating or inhibiting conceptual change and as equally important they recognized of the need to examine the classroom context to fully appreciate how these constructs play out in actual learning situations. Examining classroom context as a facet of the change process was arguably as influential as the focus on extra rational constructs. They also argued that "the classroom context may influence students' motivation and cognition and most importantly, interaction between these two constructs". The results of this research corroborate their assertion. The **model summary** table showed that the multiple correlation coefficient (R), using all the predictors simultaneously, is 0.632 and the **adjusted R^2** is 0.290, meaning that 29% of the variance in 'Physics test gain' can be predicted from the combination of 'gender, ability levels, treatment, Physics attitude, Physics motivation, Physics learning strategies perceptions, and Physics study

skills'. Note that the adjusted R^2 is lower than the unadjusted $R^2=0.400$. This is, in part, related to the number of variables in the equation.

Table 6. 12: Means, standard deviations, and inter-correlations for physics test gain and indicator variables of the experimental group (n=40)

Variable	M	SD	Gender	Ability Levels	Physics Attitude Gain	Physics Motivation Gain	Physics Strategies Gain	Physics Study Skills Gain
Physics Test Gain	10.33	10.00	-0.16	-0.60**	0.05	0.21	0.00	0.24
Predictor Variable Gender			--	0.11	-0.01	-0.12	0.15	-0.14
Ability Levels			0.11	--	0.02	-0.21	-0.02	-0.09
Physics Attitude Gain			-0.01	0.02	--	0.07	-0.04	0.22
Physics Motivation Gain			0.12	-0.21	0.07	--	0.32*	0.12
Physics Strategies Gain			0.15	-0.02	-0.04	0.32*	--	-0.04
Physics Study Skills Gain			-0.14	-0.09	0.22	0.12	-0.04	--

*p<0.05; **p<0.01
 As you can see from the coefficients Table 6.13, only ‘ability levels’ enhanced by treatment is significant (p=0.000), but the other variables will always add a little to the prediction of ‘Physics test gain’. Because several independent variables are used, a reduction of the number of variables might help us find an equation that explains more of the variance in the dependent variable, once the correction is made. It is helpful to use the concept of parsimony with multiple regressions, and use the small number of predictors needed. The ANOVA table indicates that F=3.66 and is statistically significant (p=0.007). This indicates that the combination of the predictors significantly combine together to predict ‘physics test gain’.

Table 6. 13: Multiple linear regression analysis summary for key variables used in the study predicting physics test gain of the experimental group (n=40)

Variable	B	SEB	β
Constant	130.97	32.56	-0.07
Gender	-1.32	2.78	-0.56*
Ability Levels	-8.05	1.99	0.02
Physics Attitude Gain	0.01	0.07	0.06
Physics Motivation Gain	0.04	0.10	-0.01
Physics Strategies Gain	-0.01	0.13	0.17
Physics Study Skills Gain	0.06	0.05	

Note: $R^2 = 0.40$; $F(6, 33) = 3.66$, $p = 0.007 < 0.01$; *p<0.001

The most important table is the **coefficients** Table 6.13. It shows the **standardized beta coefficients**, which are interpreted much like correlation coefficients. The *t* value and the sig. (*p*) opposite each independent variable indicates whether that variable is significantly contributing to the equation for predicting 'Physics test gain'. Thus, 'ability levels', in addition to treatment, is the only variable that is adding anything to the prediction, when the other five variables are already considered. It is important to note that the 'cognitive' (ability levels) component and the treatment contributes 60% while the rest five variables contribute 40% all together to 'Physics test gain' (see first column of correlations Table 6.12). It is important to note that all the variables are being considered together when these values are computed. Therefore, if we delete one of the predictors, even if it is not significant, it can affect the levels of significance for other predictors. For example, if we delete 'ability levels', it is quite possible that 'Physics study skills' would be a significant predictor. 29% of the variance in 'Physics test gain' is explained by the model. According to Cohen (1988) this is somewhere between medium and large effect.

In general, the model developed turn out to predict the understanding of learners with a high degree of success as 29% of the variance is explained by the model and which is somewhere between medium and large effect. Therefore, based on results of the above tables, the overarching null hypothesis of the study, H_0 , is rejected. And also the null sub-hypothesis, H_{04} , is rejected, as a result, the integrated model of conceptual change is superior to the traditional method of transmission of information in achieving deep understanding of thermodynamics content. It can also predict deep understanding successfully as shown by the regression model.

6.7 Conclusions

The results show that the integrated model of conceptual change is more effective in fostering deep conceptual and procedural understandings than the traditional transmission of information and students learn thermodynamics better in SCSMCC-based RPC method than in traditional transmission of information method. The conceptual change approach developed by integrating individual and social formation of concepts used the two sides of knowledge acquisition as a check and balance for each other and which is evolving in a spiral manner. I used mixed ability and mixed gender groups during small and whole class discussion phases of SCSMCC. I feel that such careful group formation has resulted in empowering female students and enhanced the performance of low achievers in both chapters six and seven. Alternating between group discussion and individual critical thinking in the process of learning, in a balanced or symmetrical manner allows students to restructure and change their concepts in a more efficient way. The SCSMCC believes in the power of individual mind in knowledge generation but this

should go hand in hand with sharing of information and experience with others. Neither of the two turns out to be effective when used separately. The results of this chapter support this experimental fact.

The results also showed that experimental variables predicted conceptual understanding of treatment group students with 29% of the variance in 'physics test gain' is explained by these variables. This is somewhere between medium and large effect. The regression model is, therefore, a significant predictor of conceptual understanding. The results have also shown the changes in motivation, attitude, and classroom socio-cultural contextual factors were significant in addition to knowledge change.

CHAPTER SEVEN: THE HOLISTIC MODEL OF CONCEPTUAL CHANGE: THE CASE OF CHEMICAL THERMODYNAMICS

7.1 Introduction

The treatment reported in this chapter was conducted one month after the physical thermodynamics treatment reported in chapter six. One may well ask that why you need to repeat the treatment in two closely similar contexts on the same group of students. The answer is because of the two-fold purpose of the research: (1) I wanted to study the issue of knowledge transfer, in addition to conceptual change, from physical to chemical thermodynamics within an interval of one month, (2) to put the testing and results obtained on a non-trivial basis regarding conceptual change thereby ensuring the validity of the model beyond any reasonable doubt. The purpose of this chapter is to show how the conceptual change approach enhanced deep understanding, empowered female students, increased the performance of low achievers, and predicted deep understanding of chemical thermodynamics from combinations of motivational, affective, socio-cultural contextual factors, treatment and achievement levels. The results discussed include: the effect of conceptual change approach in fostering deep understanding of grade 12 chemical thermodynamics unit, empowering female students using the conceptual change approach in learning grade 12 chemical thermodynamics unit, the advantage of conceptual change approach in enhancing the performance of low achievers in grade 12 chemical thermodynamics unit and prediction of deep understanding of grade 12 chemical thermodynamics unit from a combination of extra rational constructs, treatment and achievement levels. APA style tables on gains and bar graphs on total scores illustrate the results throughout the chapter. The results are quoted as evidence to show superiority of the SCSMCC-based RPC method over the traditional transmission of information method.

7.2 Checking for Assumptions

The Exploratory Data Analysis (EDA) by way of generating numbers from the data instead of generating plots was used. Table 6.1, shows that all of the variables which were measured with five levels have skewness values between -1 and 1 and hence they are normally distributed. We can, thus, assume that they are more or less like scale variables rather than ordinal variables. Therefore, we can use parametric statistics that have the assumption of normality. Some parametric statistics are "robust" or the assumptions of normality can be violated without damaging the validity of the statistic (examples are t-test and ANOVA). Non parametric statistics are used when the assumptions of parametric statistic are violated, they do not require normal distribution of variables or homogeneity/equality of variances.

7.3 The Effect of Conceptual Change Approach in Fostering Deeper Understanding of Grade 12 Chemical Thermodynamics Unit

In this section I will compare the effect of conceptual change approach with the traditional transmission of information approach in fostering deeper understanding of Grade 12 chemical thermodynamics unit. Pintrich and his associates (1993) brought a broader view of the learner, one in which cognitive and extra rational constructs operate in a dynamically interacting way in the study of knowledge restructuring. They simply wanted to see how extra rational constructs might play a role in fostering knowledge change. They did not envisage how extra rational constructs themselves might change. According to them, extra rational constructs are complex, multidimensional constructs that interact in dynamic ways with cognitive constructs such as background knowledge and metacognition. If extra rational constructs are dynamically interacting with cognitive constructs it is also highly likely that they themselves be affected or changed in the change process. Pintrich and associates (1993) only saw their importance in knowledge change or their role in facilitating conceptual change but not how they themselves might change in the process of creating the whole child rather than the cognitive child. They also asserted that it is no longer important to do research on learning as occurring in the cold setting of the laboratory that can only examine the cold constructs of cognitive information processing and according to these authors "the new view of learning is one that is more contextual, cultural, social, and affective as well as cognitive" (Pintrich et al, 1993). Epistemological beliefs, interest, domain differences, classroom contexts, social and cultural contexts should be considered in conceptual change learning. Conceptual change is now viewed as a complex and dynamic interaction of affective, motivational and socio-cultural contexts. According to them, much work is needed to explicate this new view and extend the research agenda for conceptual change. This is actually the purpose of this research which tried to come up with the model these authors called upon to be developed by future researchers almost two decades ago. A number of models such as CRKM (Cognitive Reconstruction of Knowledge Model) and CAMCC (Cognitive-Affective Model of Conceptual Change) were developed to deal with issues of conceptual change learning since Pintrich and associates land mark article of 1993. My SCSMCC takes the research on conceptual change one step further by requiring extra rational constructs themselves change instead of only facilitating knowledge or cognitive change. This makes SCSMCC a truly "hot" model of conceptual change.

The design I used is predominantly a non-equivalent group's quasi-experimental design in which two intact classrooms were purposely selected from Bole secondary and preparatory school Grade 12 students. The selected sections were 05 and 06. These two sections were found to be almost similar in their Grade 11 final exam results ability distributions when checked for all sections the teacher who agreed to participate handles. This is done to minimize the non-equivalence of comparison and experimental groups

in our purposive selection right from the outset. In my research I, not only, required the involvement of "hot" constructs but also their change. The gain is the difference between the post test/administration and the pre-test/administration of all the five continuous variables used in the study.

In implementing the model I developed six phases of the model. In *Phase 1 of SCSMCC (Engaging the Door Keepers--Motivation, Affection, and socio-cultural contextual factors)*: teacher introduces the topic of the lesson while at the same time motivating and arousing their curiosity and interest in the topic. The RPC strategy used was based on SCSMCC. In this strategy the teacher starts the lesson by motivating and nurturing interest in the particular topic. For example, by telling a history of the particular scientist who contributed to the topic under study, some self-efficacy, a belief that we can, stories from the teacher or a capable peer, etc. This should be done in a short and precise manner for the purpose of not wasting class time. The teacher should control the class and students are required to actively listen. Teacher writes the two categories of valid and invalid conceptions side by side on the blackboard and asks students to decide through argument, evidence and justification as to which category they think is the scientifically correct and valid conception (5 minutes). The word "misconception" or invalid conception refers to: (1) students' mistaken answers to a particular situation, (2) students' ideas which cause mistaken answers about a particular situation, and (3) students' beliefs about how the world works different from that of the scientists' " (Dykstra et al., 1992). If a student holds misconceptions, these misconceptions interfere with subsequent learning. Even though we used the door keepers in the introduction, the teacher should continue to engage them throughout the class time. In this way we can see how they are themselves changing in addition to assisting in knowledge restructuring and change.

From phase two (*the initial personal thinking phase*) onwards, students individually organize their background knowledge and attempt to relate to the learning task by giving own explanations and taking positions. This helped them to effectively engage in classroom discussions and finally critically reflect on their learning experiences which in turn helped them to apply their deep knowledge to solve problems. This showed that classroom contextual factors are important in knowledge restructuring.

Table 7.1, compares experimental and comparison groups on key variables used in the study along with skewness statistic values for each variable. I checked for skewness to see if the variables are normally distributed regarding their gain scores. The means with in each of the five pairs look different. These differences could be due to chance and therefore I need to check the differences using the t-test. The independent samples t-test shows that the F-test (Levene test) is significant only for 'Chemistry attitude gain' and 'Chemistry perception gain' variables and for these variables the assumption of

homogeneity/equality of variance is violated and the **equal variance not assumed** lines should be used for the t-test and related statistic. SPSS adjusts the t, df and significance (Sig.) for this case. Thus, for 'Chemistry attitude gain' variable, the appropriate $t=-0.42$, degrees of freedom (df) =69.84, and $p=0.673$. This t is not statistically significant, so we can say that comparison and experimental group students did not have difference in Chemistry attitude gain scores. This could be due to students' feeling after filling the attitude questionnaires for the 4th time in a semester or feeling created by their background which has not been changed. Background feeling or knowledge can either facilitate or inhibit changes in knowledge or attitude (Pintrich et al., 1993). Similarly, for 'Chemistry perception gain' variable, the appropriate $t=3.01$, degrees of freedom, df =46.34, and $p=0.004$. This t is statistically significant, so we can say that experimental and comparison group students did have difference in 'Chemistry learning strategies perception gain' scores. Students in the two groups did have non-significant positive difference in their study skills gain scores as well. On the other hand, Chemistry test gain ($p=0.000$), Chemistry motivation gain ($p=0.001$) and Chemistry learning strategies perception gain ($p=0.004$) are statistically significant because their $p<0.05$. The results show that both extra rational/"hot" constructs and "cold"/rational constructs have been changed as a result of the treatment. Therefore, the SCSMCC as integrated model of conceptual change clearly showed the dynamic interaction and functional interdependence of "hot" and "cold" constructs. And we need to balance cognitive factors with socio-cultural contextual factors which make SCSMCC a somehow comprehensive model of conceptual change.

Table 7. 1: Comparing experimental and comparison groups on key variables used in the study ($n_{EG}=40$ and $n_{CG}=40$)

Variable	M	SD	MD	t	df	p	Skewness Statistic
Chemistry Test Gain			10.80	6.45	78	0.000*	-0.37
Experimental Group	13.50	6.11					
Comparison Group	2.70	8.65					
Chemistry Attitude Gain			-1.50	-0.42	69.84**	0.673	-0.10
Experimental Group	1.23	12.83					
Comparison Group	2.73	18.32					
Chemistry Motivation Gain			10.68	3.43	78	0.001*	-0.08
Experimental Group	10.28	12.60					
Comparison Group	-0.40	15.14					
Chemistry Strategies Gain			11.03	3.01	46.34**	0.004*	-0.81
Experimental Group	0.90	6.82					
Comparison Group	-10.13	22.14					
Chemistry Study Skills Gain			9.13	1.20	78	0.236	0.26
Experimental Group	7.78	34.77					
Comparison Group	-1.35	33.53					

*The calculated p value is significant at $\alpha=0.05$

***The t and df were adjusted because variances were not equal*

When a statistically significant outcome does not give information about the strength or size of the outcome, Cohen's (1988) Effect Size (d) is used. Effect size measures the strengths of the relationship between the independent variable and the dependent variable and/or the magnitude of the difference between levels of the independent variable with respect to the dependent variable. The effect sizes are expressed in standard deviation units. Usually effect sizes vary from 0 to ± 1 but can be more than 1. Cohen (1988), provided guidelines for interpreting the size of the "effect" for effect size measurement such as d, based on effect sizes usually reported in studies in the behavioral sciences and education. They are classified large (or larger than typical), which is 0.80, medium (or typical), which is 0.50, and small (or smaller than typical), which is 0.20. If $d \geq 1$ (uncommon) it is much larger than typical. The effect size indicates the strength of the relationship and, thus, the relevant practical significance. Thus for full interpretation of t-tests we need Table 7.1 with means and standard deviations to compute the effect size. The calculated d for: chemistry test gain is 1.44; for chemistry attitude gain is 0.12 which is smaller than typical and this could be due to background feeling created by treatment of 'Physical Thermodynamics' which sometimes inhibit changes in their affective feeling. We should note that sometimes background feeling not only facilitate change but also has the capacity to inhibit changes. And for chemistry motivation the gain is 0.77 which is a large effect; for chemistry perception of learning strategies the gain is 0.69 which is between typical (medium) and large effect; and for chemistry study skills the gain is 1.63 which is much larger than typical. Except for chemistry attitude gain which has small effect the other variables has high effect sizes.

Conceptual change is now viewed as a complex and dynamic interaction of cognitive, affective, motivational and socio-cultural contextual factors (Pintrich et al., 1993). This kind of complex and dynamic interaction of individual cognitive factors and socio-cultural contextual factors will not result only in knowledge change but also in changes of motivational, affective and socio-cultural contextual factors themselves. This work is needed to explicate this new view and extend the research agenda for conceptual change. The results above show that recognition of affective, situational (contextual), and motivational factors in addition to cognitive factors help in developing the whole child. The exclusion of extra rational factors or "hot" constructs will only lead to the cognitive child only. In my research I, not only, required the involvement of "hot" constructs but also their change. The gain is the difference between the post test/administration and the pre-test administration of all the five continuous variables used in the study.

In Phase 1 of SCSMCC (Engaging the Door Keepers--Motivation, Affection, and socio-cultural contextual factors) clearly showed how the extra rational constructs are involved right from the beginning of implementation of the model and sustained throughout the lesson and from phase two (the initial personal thinking phase) onwards, students individually organize their background knowledge and attempt to relate to the learning task by giving own explanations and taking positions. This helped them to effectively engage in classroom discussions and finally critically reflect on their learning experiences which in turn, helped them to apply their deep knowledge to solve problems. This showed that classroom contextual factors are important in knowledge restructuring.

The results above showed that there are significant changes in Thermodynamics achievement tests, science motivation, learning strategies perceptions. Even though there are no significant changes, the graphs and tables have shown that there are changes in students' study skills. There are no significant changes in science attitude which could be due to background feelings imported from Physical Thermodynamics which negatively affected Chemical Thermodynamics attitudinal change. Except attitude, both "cold" and "hot" constructs have significantly changed. This shows that the SCSMCC is really a somewhat more comprehensive model than CRKM and CAMCC models which involve extra rational constructs but which did not require them to change. The authors of CRKM (Cognitive Reconstruction of Knowledge Model) and CAMCC (Cognitive-Affective Model of Conceptual Change) took the "hot" constructs as constant during the instructional process but SCSMCC (Spiral Cognitive-Sociocultural Model of Conceptual Change) considers the "hot" constructs as dynamic and responsive to the cognitive and socio-cultural environment of learning functionally unified in a symmetric manner using the spiral as a bridge between them. This experimental fact is also shown using post test/administration total scores and pre test/administration total scores in figures 7.1 to 7.5.

The figures are simply alternative ways, to tables, of visualizing changes in the five continuous variables and discrete factors such as gender used in the study. We should carefully plan learning experiences intended for independent learning and those for group/collaborative learning increasing their level of sophistication each time they are repeated in the spiral cycle. The spiral concept is not only applicable to classroom learning but also in developing a high school science curriculum in which concept should be presented with increasing depth and more subtle examples across hierarchy of grades. We know that some concepts are repeated at various grade levels and they should be carefully vertically coordinated, say, from ninth grade to twelfth grade. The SCSMCC has also implications for educational policy development in which the pedagogy of learning should require a more careful and balanced approach between individual/personal development and societal development. The spiral is everywhere in nature, most of the galaxies in the universe are spiral in shape and spirals are evident on our heads which are

visible when our hairs are cut short. We can cite multitude of examples of development in which the process evolves in a spiral manner.

Figure 7.1, compares the pre-test and post-test mean total scores of the comparison group and experimental group. Table 7.1 compares the two groups using their mean gain scores. The graphs complement the table by providing mean total scores of the two groups. The graphs show that there are almost no differences in the mean pre-test scores. The initial difference between the two groups is -0.30 on a scale of 54 in Chemical Thermodynamics achievement test. This could be due to the ANCOVA used to adjust for initial differences. The scale is 54 means that the tests are scored out of maximum interval score of 54. The final difference between the two groups on mean post-test scores is 2.68 on the same scale of the test, which is significant difference. Both the mean total score comparisons using graphs and the mean gain score comparisons using tables corroborate that there is a significant difference between the two groups regarding chemical thermodynamics achievement. The graph shows that rational factors were almost the same in the pre-test but due to treatment of SCSMCC as comprehensive model of conceptual change and accompanying RPC method the experimental group outperformed the comparison group in the post-test.

In Phase six of SCSMCC (Deep Understanding): demonstration of deep understanding by solving problems which resemble real life situations was shown. Application of his/her knowledge in solving problems demonstrates his/her deep understanding of the topic or learning task (10 minutes). This phase reveals whether conceptual change has really occurred. The results have shown that experimental group students achieved significant gain over their comparison group counter parts. The spiral in the model bridges and balances individual and social formation of concepts in a continuous manner and the deep understanding location is shown along the axis of learning at end of each cycle. This shows that the SCSMCC as holistic model of conceptual change is really a valid model in bringing about conceptual change as the relative achievement result mentioned above has shown.

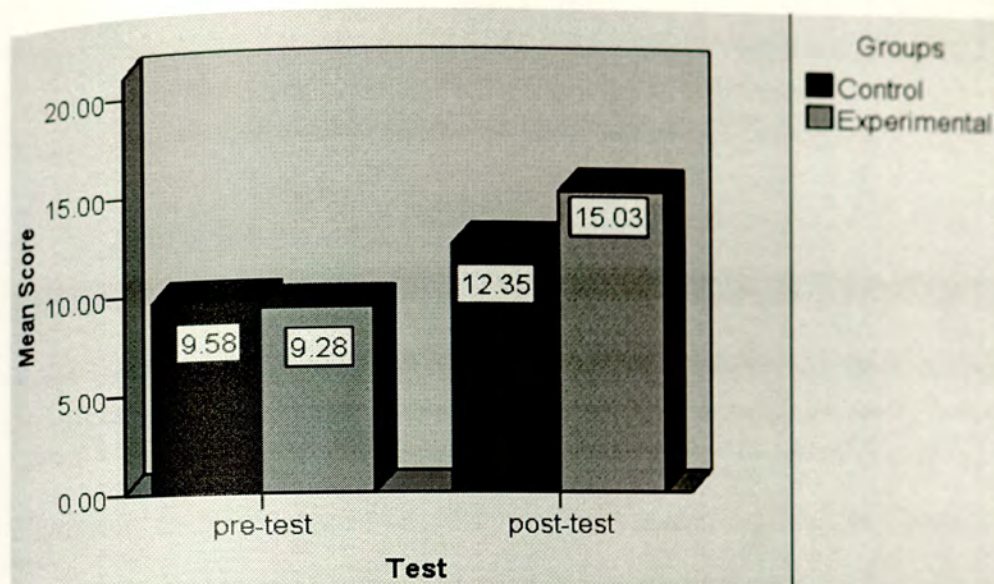


Figure 7. 1: Mean difference in chemistry achievement between experimental and comparison groups

Figure 7.2, shows the mean difference in attitude towards chemistry between experimental and comparison groups in pre-administration of attitude towards physics questionnaire. The final difference between the two groups on mean post-administration scores of attitude towards physics is 6.92 on a scale of 160 in pre-administration of attitude towards physics questionnaire. The scale is 160 means this is the maximum interval score of science attitude scale. There is no significant change between the initial and the final administration of the attitude scale. Both the mean total score comparisons using graphs and the mean gain score comparisons using tables corroborate that there is no significant difference between the two groups regarding their attitude towards chemistry. The graph shows that affective/attitudinal factors were almost the same in the pre-administration and also the affective/attitudinal changes are non-significant for both the experimental and comparison groups in post-administration as well. This means that the treatment had no effect on changing student attitude which means that the background attitude from Physical Thermodynamics had the effect of neither facilitating nor inhibiting the student attitude in Chemical Thermodynamics. Therefore, as shown in phase one of SCSMCC, nurturing positive affection of the subject matter throughout the classroom period will result in attitudinal change besides facilitating conceptual change if not use the treatment twice.

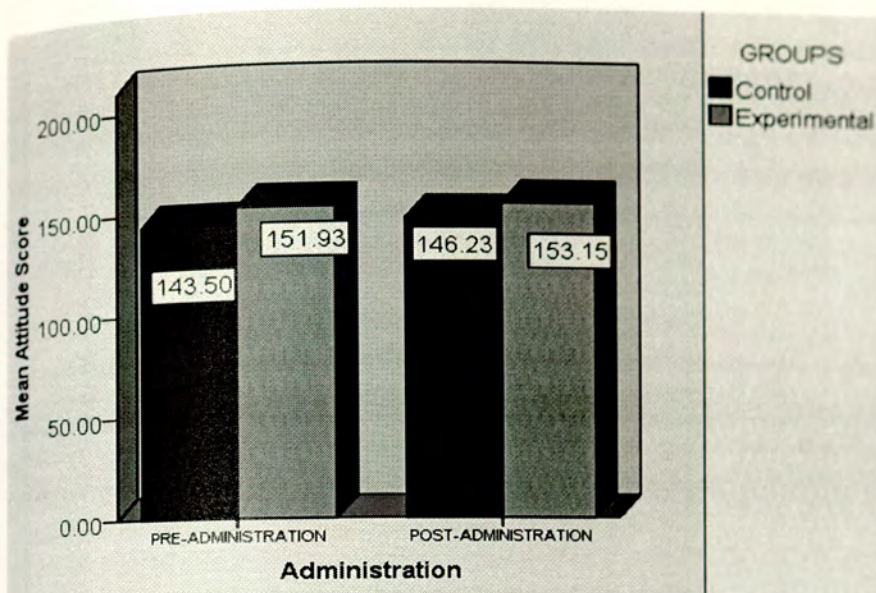


Figure 7. 2: Mean difference in attitude towards chemistry between experimental and comparison groups

Figure 7.3, shows the mean total scores difference in chemistry motivation between comparison and experimental groups. The initial mean difference between the two groups in pre-administration of science motivation questionnaire is -1.00 on a scale of 120. The scale is 120 means this is the maximum interval score of science motivation scale. The final mean difference between the two groups in post-administration of science motivation questionnaire is 9.67 on the same scale, which is significant difference. Both the mean total score comparisons using graphs and the mean gain score comparisons using tables corroborate that there is a significant difference between the two groups regarding motivation for chemistry learning. The graph shows that the key factor of motivation for science teaching is almost the same in pre-administration of the treatment but the motivation has shown significant change for the experimental group but no significant change for the comparison group. The change in student motivation is one of the key achievements of this research as a result of SCSMCC as integrated model of conceptual change and accompanying RPC method which required all cognitive and motivational factors to be changed in the development of the whole child. This means that the treatment positively motivated or changed student motivation which is what we want to happen in any science teaching. Therefore, as shown in phase one of SCSMCC, nurturing positive motivation of the subject matter throughout the classroom period will result in motivational change besides facilitating conceptual change.

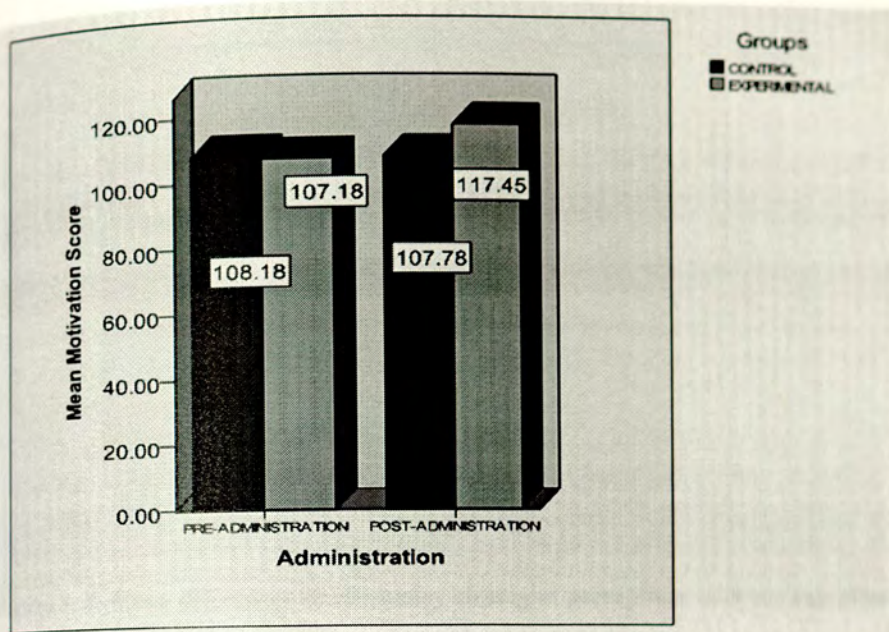


Figure 7. 3: Mean difference in chemistry motivation between experimental and comparison groups

Figure 7.4, shows mean total scores difference in chemistry learning strategies perceptions between comparison and experimental groups. The initial mean difference between the two groups in pre-administration of students' chemistry learning strategies perceptions is 4.63 on a scale of 80. The scale is 80 means this is the maximum interval score of science learning strategies perceptions scale. The final mean difference between the two groups in post-administration of students' chemistry learning strategies perceptions is 15.65 on the same scale. As the difference between the final and initial differences is 11.02, the change is significant as shown in the tables for mean gain scores on perceptions of chemistry learning strategies. Student perceptions of learning strategies even decreased for the comparison group as shown in the Figure 7.4, however, there is significant change between experimental and comparison groups as it is self-evident from the graph. The SCSMCC as holistic model of conceptual change and accompanying RPC method have somehow impressed the students as there are changes in their perceptions. This means that the treatment positively affected or changed student perceptions or beliefs about learning strategies. Therefore, as shown in phase one of SCSMCC, nurturing positive perceptions of learning strategies throughout the classroom period will result in perceptual and belief changes besides facilitating conceptual change.

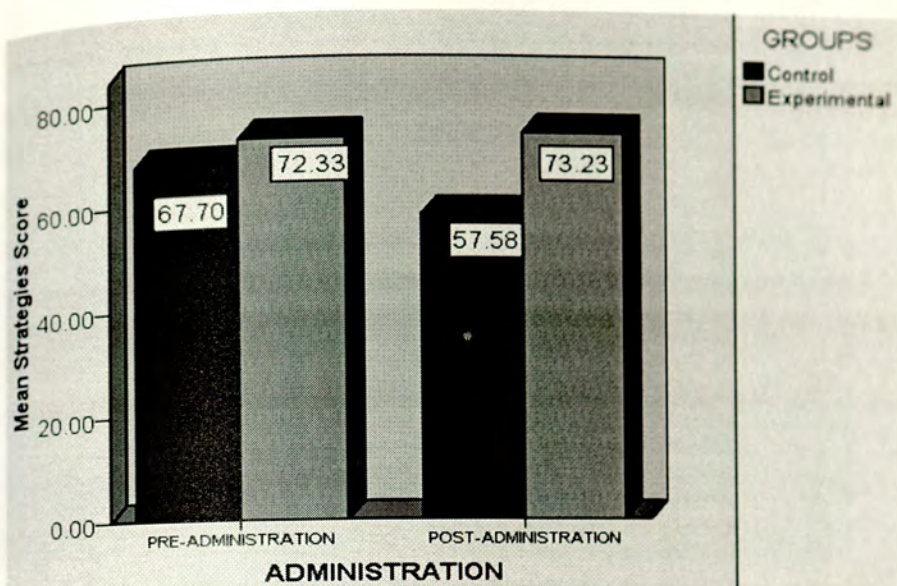


Figure 7. 4: Mean difference in chemistry strategies perceptions between experimental and comparison groups

Figure 7.5, shows mean total scores difference in chemistry study skills between comparison and experimental groups. The initial mean difference between the two groups in pre-administration of students' study skills total scores is 1.50 on a scale of 204. The scale is 204 means this is the maximum interval score of science study skills scale. The final mean difference between the two groups in post-administration of students' study skills total scores is 10.62 on the same scale. On such a large scale the total difference of 9.12 between the final and the initial administrations is insignificant as shown in Table 7.1 for mean gain scores on students' study skills. Student study skills is almost constant for the comparison group as shown in Figure 7.5, however, even though it is not significant the change in the experimental group is self-evident from the graph. As a result of the SCSMCC as comprehensive model of conceptual change and accompanying RPC method, the students have somehow reconsidered and changed the way they study as there are changes in their study skills. This means that the treatment positively affected or changed student study habits and skills. Therefore, as shown in phase one of SCSMCC, nurturing systematic and effective study skills of the subject matter throughout the classroom period will result in changes of their study skills besides facilitating conceptual change.

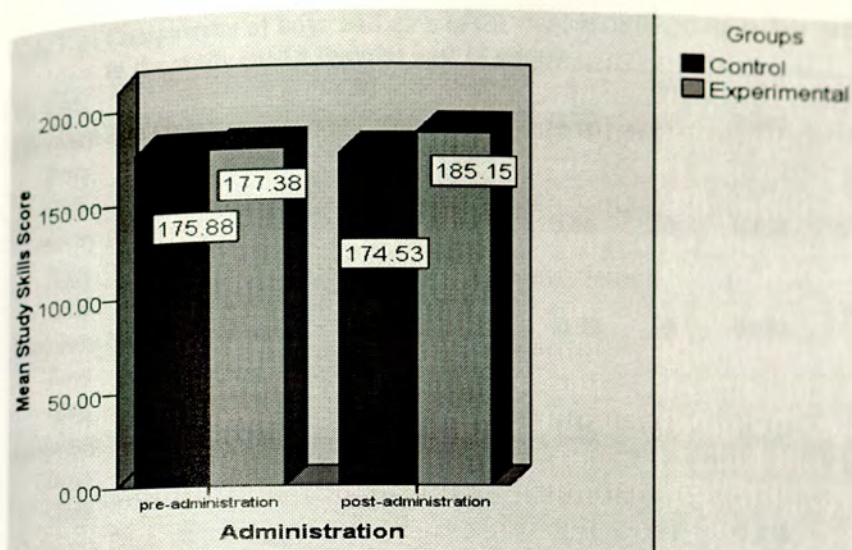


Figure 7. 5: Mean difference in chemistry study skills between experimental and comparison groups

Therefore, based on results of the above tables and graphs, the overarching null hypothesis of the study, H_0 , is rejected. And also the sub-null hypothesis, H_{01} , is rejected. The results show that the integrated model of conceptual change and its accompanying RPC method is more effective than the traditional transmission of information method and students learn thermodynamics better in SCSMCC-based RPC method than in traditional transmission of information method.

7.4 Empowering Female Students Using the Conceptual Change Approach in Learning Grade 12 Chemical Thermodynamics Unit

The purpose of this section is to show how the conceptual change approach empowers female students compared to the traditional transmission of information method. Normality test shows that t-test can be applied to compare means between males and females of comparison and experimental groups. As Table 7.2, shows Levene's test for equality of variances (or F-test) is not significant and hence the 'the equal variance assumed line' can be used for all the variables on which means of male and female of experimental group are compared. The two tailed t-test is not significant for all the variables ($P_t > 0.05$) and hence there is no significant difference between male and female within the experimental group. There is no gender difference in experimental group students regarding the treatment and all other variables on which measurement have been taken. SCSMCC as holistic model of conceptual change and the accompanying RPC method forms groups on the basis of mixed ability and mixed gender and this could be the reason why there is no gender differences in all variables used for the experimental group.

Table 7.2 : Comparison of boys and girls of the experimental group on key variables used in the study (n=18 females and 22 males)

Variable	M	SD	t	df	p	Mean Difference
Chemistry Test Gain			0.78	38	0.443	1.52
Boys	12.82	5.47				
Girls	14.33	6.89				
Chemistry Attitude Gain			0.66	38	0.512	2.72
Boys	-2.84	11.20				
Girls	3.55	14.78				
Chemistry Motivation Gain			-0.70	38	0.488	-2.82
Boys	10.11	13.51				
Girls	10.40	11.58				
Chemistry Strategies Gain			1.26	38	0.22	2.71
Boys	0.36	6.90				
Girls	1.38	6.61				
Chemistry Study Skills Gain			1.15	38	0.258	12.63
Boys	5.68	34.61				
Girls	8.85	34.64				

There are no significant ($p_s > 0.05$) gender differences in all variables as shown in Table 7.2. The mean difference between female and male of the experimental group students in: chemistry test gain is 3.15; chemistry attitude gain is 0.22; chemistry motivation gain is 3.57; chemistry learning strategies perceptions gain is -3.43; and chemistry study skills gain is 7.32 on their respective scales. And all of these differences have been found to be not significant. Even though the differences are not significant, the female students showed higher measurement values in all variables, except in 'chemistry motivation gain' variable than their male counterparts. In chemistry test gain female students scored 14.33 and male students scored 12.82 on the average. Female students outperformed their male counterparts by 1.51 average points in chemistry test gain. In chemistry attitude gain female students scored 3.55 and male students scored -2.84 on the average. Female students have shown more positive affection for chemistry by 6.39 average points compared to their male counterparts. In chemistry motivation gain female students scored 10.40 and male students scored 10.11 on the average. Female students were almost the same as male students in their motivation towards chemistry. In chemistry strategies perception gain male students scored 0.36 and female students scored 1.38 on the average. In this case female students have shown more positive perception than male students by 1.02 average points. In chemistry study skills gain female students scored 8.85 and male students scored 5.68 on the average. Female students had a more positive and effective study skills than male students by 3.17 average points. Similar t-test for the comparison group has shown that there are no gender differences in all variables mean gains except for 'chemistry learning strategies perceptions' variable. The perceptions variable shows $P=0.034 < 0.05$ which is

significant for the comparison group. The traditional transmission of information method definitely segregate's students on gender basis at least as far as perceptions of their learning strategies is concerned.

Table 7. 3: Comparison of boys and girls of the comparison group on key variables used in the study (n=24 females and 16 males)

Variable	M	SD	t	df	p	Mean Difference
Chemistry Test Gain			0.45	38	0.655	1.27
Boys	1.94	9.77				
Girls	3.21	7.99				
Chemistry Attitude Gain			-1.42	38	0.156	-8.27
Boys	1.56	16.87				
Girls	6.01	16.84				
Chemistry Motivation Gain			-0.18	38	0.861	-0.88
Boys	-0.83	13.40				
Girls	-0.19	16.47				
Chemistry Strategies Gain			-2.20	38	0.034*	-15.00
Boys	-4.19	25.42				
Girls	-16.84	17.78				
Chemistry Study Skills Gain			-0.59	38	0.560	-6.42
Boys	9.00	34.14				
Girls	4.14	33.60				

**The calculated p value is significant at $\alpha=0.05$*

Figure 7.6, compares the pre-test and post-test mean scores of female and male of comparison and experimental groups. Tables 7.2 and 7.3 have shown that there are no gender differences within experimental group and comparison group regarding mean achievement gain scores. The pre-test mean difference between males of comparison group and experimental group is -1.76 on a scale of 54. The post-test mean difference between males of experimental group and comparison group is 4.12. The pre-test mean difference between females of experimental group and comparison group is -1.83 on a scale of 54. The post test mean difference between females of experimental group and comparison group is 1.54. In both cases, the pre-test mean differences are not significant but the post-test mean differences are significant which is a computable result with Table 7.2 in overall differences between the two groups. Flossie-Asekanao Gomile-Chdyaonga (2003) case study report had shown that boys outperform girls in science and mathematics education and the differential between boys and girls is widest in mathematics and science subjects. According to the report, there are curricular biases and inherited socio-cultural factors which marginalize girls in science subjects. Appropriate methodologies of teaching which empower girls result in gender balance in science subjects. But results in this research have shown that girls are not inferior in these subjects. And this could be due to the application of my SCSMCC as integrated model of conceptual change and accompanying RPC method which involved not only

cognitive factors but also other extra rational factors such as motivation, attitude and socio-cultural contextual factors.

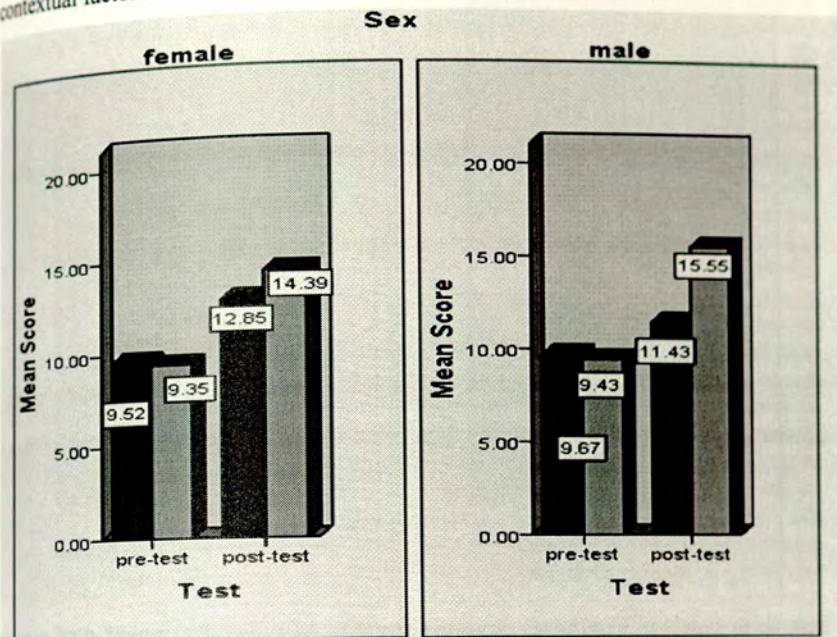


Figure 7. 6: Mean difference in chemistry achievement between male and female of the two groups

Figure 7.7, compares the pre-attitude and post-attitude mean scores of female and male of experimental group and comparison group. Tables 7.2 and 7.3 have shown that there are no gender differences within experimental group and comparison group regarding mean attitude gain scores. The pre-attitude mean difference between males of experimental group and comparison group is 7.94 on a scale of 160. The post-attitude mean difference between males of experimental group and comparison group is 3.54 on the same scale. The pre-attitude mean difference between females of experimental group and comparison group is 11.45 on a scale of 160. The post-attitude mean difference between females of experimental group and comparison group is 9.01. in both cases, the post-attitude test mean difference are lower than the pre-test results, which corroborates the result of Table 7.2 on overall difference between the two groups regarding changes in attitude. Negative affect or attitude is related to resistance to new conceptions. Pintrich and associates (1993) also proposed that epistemological beliefs should also be related to knowledge change. Epistemological beliefs are individual's beliefs about the nature of knowledge and the process of knowing. This negative affect may be related to the background feeling developed in Physical Thermodynamics in which they have shown attitudinal change and kept that change constant after wards which inhibited attitudinal change in Chemical Thermodynamics.

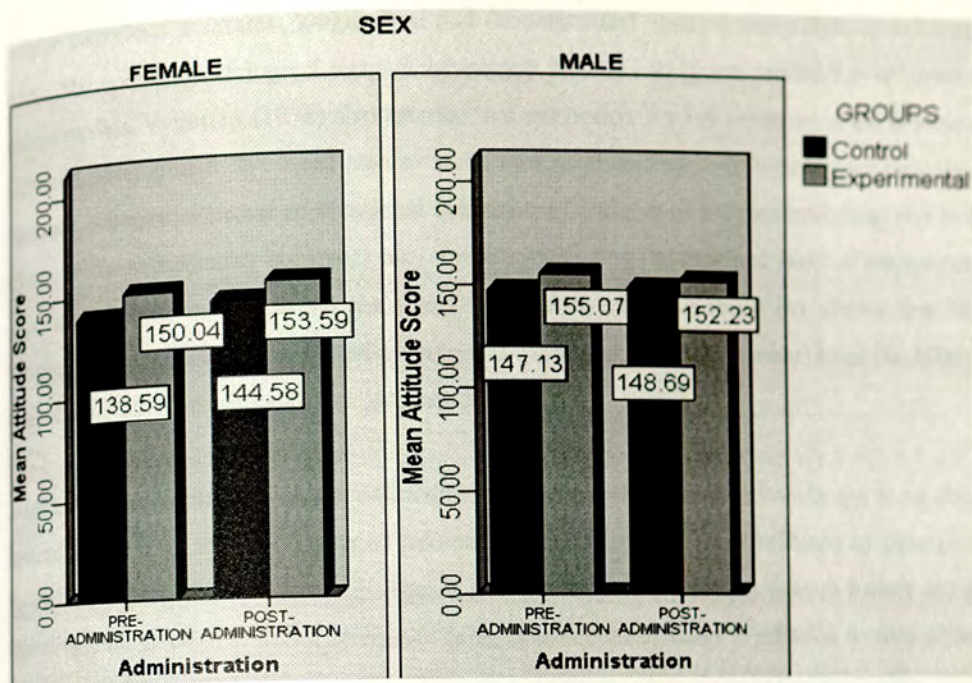


Figure 7. 7: Mean difference in attitude towards chemistry between male and female of the two groups

Figure 7.8, compares the pre-motivation and post-motivation mean scores of female and male of experimental group and comparison group. Tables 7.2 and 7.3 have shown that there are no gender difference within experimental and comparison groups regarding mean chemistry motivation gain scores. The pre-motivation mean difference between females of experimental group and comparison group is -1.42 on a scale of 120. The post-motivation mean difference between females of experimental group and comparison group is 9.17 on the same scale. The pre-motivation mean difference between males of experimental group and comparison group is -0.37 on a scale of 120. The post-motivation mean difference between males of experimental group and comparison group is 10.57 on same scale. In both cases, the pre-motivation mean differences are not significant but the post motivation mean difference are significant, which corroborates the results of Table 7.2 on overall difference between the two groups regarding changes in motivation.

Motivation is a key factor in conceptual change instruction and I tried to see its change between pre-administration of treatment and post-administration of treatment. Both the female and male of the experimental group showed higher motivation than those of comparison group during post-administration of science motivation questionnaire but there are no gender differences in motivation. Pintrich(1999) also noted that promoting a mastery orientation, awareness of goals and beliefs by students, and teaching self-regulatory strategies should have a concomitant effect on the change process. He called for experimental,

reliable behavioral measures, longitudinal and developmental research rather than co relational research which has more methodological rigor. It is unlikely that we can ignore motivation in future conceptual change models. Vygotsky (1978) also asserted that motivation is a key construct in the process of learning and child development. We need also to study how motivational constructs trigger conceptual change. Evidence is needed whether motivational constructs play direct or indirect/mediating role in knowledge change. Indirect/mediating construct play a role by affecting the type and level of engagement with the information which in turn affect the likely hood of change. The result has shown that SCSMCC as comprehensive model of conceptual change and accompanying RPC method have the effect of raising student motivation which facilitates learning of science.

Indeed, "learner's epistemic goals, defined as "their motivations towards knowledge as an object" have a mediating effect on the processing of information and ultimately, the likelihood of conceptual change" Pintrich and associates (1993:p.172). That is how the SCSMCC has used student beliefs and perceptions regarding their goals of learning science to enhance conceptual change in addition to motivation.

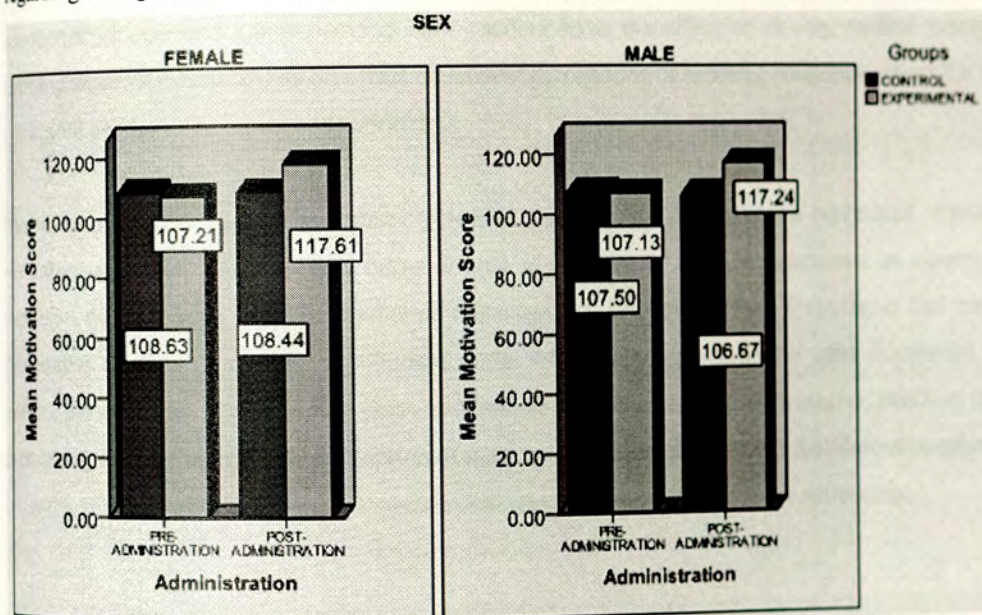


Figure 7.8: Mean difference in chemistry motivation between male and female of the two groups

Figure 7.9, compares the pre-perception and post-perception mean scores of female and male learning strategies of experimental group and comparison group. Table 7.2 has shown that there are no gender differences within experimental group but there is gender difference within comparison group regarding mean physics perception of learning strategies gain scores. The pre-perception of learning strategies mean difference between females of experimental group and comparison group is -1.99 on a scale of 80. The

post- perception of learning strategies mean difference between females of experimental group and comparison group is 15.23 on the same scale. The total difference between the pre- perception and post- perception is 11.23, which shows that the difference between females of the two groups is significant when taken in an overall manner. The pre-perception of learning strategies mean difference between males of experimental group and comparison group is 11.23 on a scale of 80. The post- perception of learning strategies mean difference between males of experimental group and comparison group is 16.16 on same scale. In each case, the pre-perception mean differences are not significant for females of the two groups and the pre-perception mean difference is not significant for males of the two groups as well. In both cases, the post-perception mean differences are significant, which corroborates the results of Tables 7.2 and 7.3 on overall difference between the two groups regarding learning strategies perceptions.

Both the female and male of the experimental group showed higher perceptions than those of comparison group during post-administration of learning strategies questionnaire but there are no gender differences in their perceptions of learning strategies. The result has shown that SCSMCC as integrated model of conceptual change and accompanying RPC method have the effect of raising student perceptions of learning strategies. Gender has no effect on student perceptions of learning strategies means the study has controlled gender as an extraneous variable.

Motivational constructs such as learner perception of learning strategies are embedded within specific classroom contexts. Students who adopt a goal of mastery of content mentioned in student learning strategies questionnaire use more elaborate metacognitive and self-regulatory strategies that lead to deep processing of the information. In contrast, those who adopt a performance goal orientation focus on getting the grade or outperforming peers and tend to use more superficial strategies, resulting in shallow processing of information. Thus, adoption of mastery goal orientation should facilitate conceptual change. Students with different achievement goals would approach knowledge change differently.

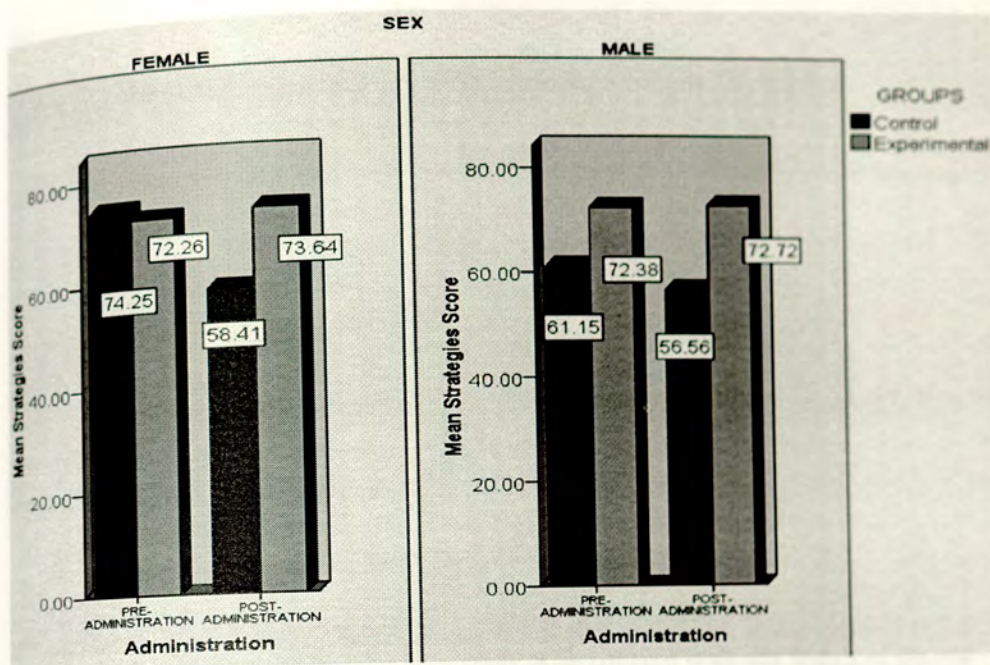


Figure 7.9: Mean difference in chemistry learning strategies perceptions between male and female of the two groups

Figure 7.10, compares the pre-study skills and post-study skills mean scores of female and male study skills of experimental group and comparison group. Tables 7.2 and 7.3 have shown that there are no gender difference within experimental group and comparison group regarding mean chemistry study skills gain scores. The pre-study skills mean difference between females of experimental group and comparison group is 6.81 on a scale of 204. The post-study skills mean difference between females of experimental group and comparison group is 11.52 on the same scale. The pre-study skills mean difference between males of experimental group and comparison group is -4.37 on the same scale. The post-study skills mean difference between males of experimental group and comparison group is also 10.30 on same scale, which shows that there is no change in study skills between pre-study skills and post-study skills, while there is a change in females study skills between experimental group and comparison group. Overall there is no significant difference between the experimental group and comparison group in their study skills, which corroborates the results of Tables 7.2 and 7.3 on overall difference between the two groups regarding chemistry study skills. This variable was included in the study to see if it significantly affects the outcome of the study but as expected this variable is effectively controlled as a confounding variable but there are no gender differences in study skills. The equality of the different sexes could be due to SCSMCC as comprehensive model of conceptual change and accompanying RPC method which used mixed ability and mixed gender groups which are more willing to share knowledge and persuade each other.

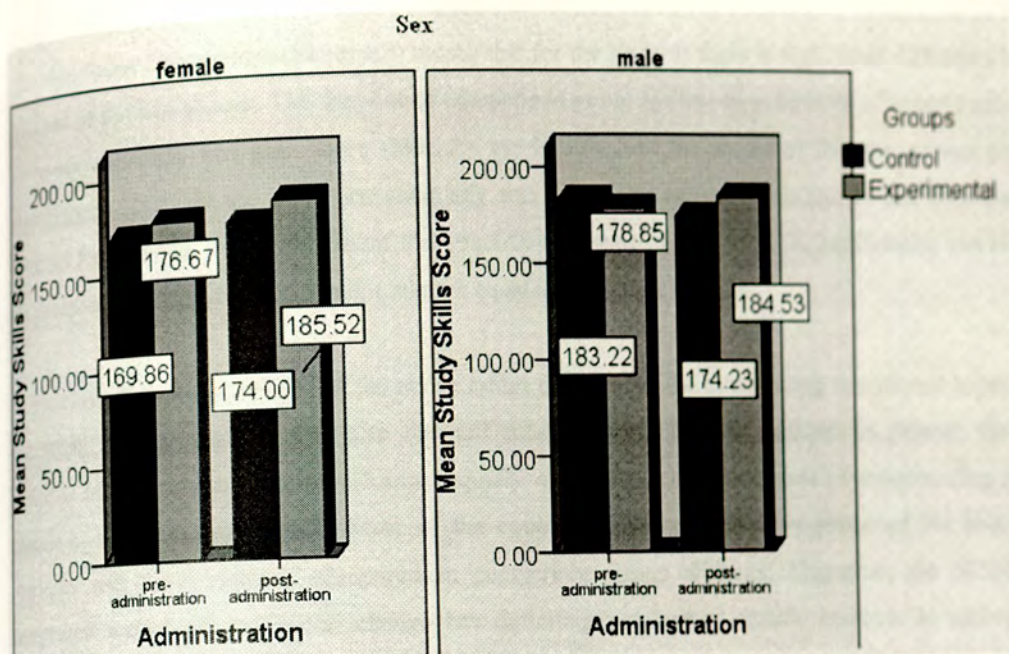


Figure 7. 10: Mean difference in chemistry study skills between male and female of the two groups

Table 7.4 shows the summary of results depicted in tables 7.2 and 7.3 regarding gender wise understanding of chemical thermodynamics unit three of grade 12 chemistry. The mean difference between experimental group and comparison group male students is 10.88 and the mean difference of that of female students is 11.12 average gain points. Therefore, we can conclude that female students better performed and empowered by the conceptual change approach in achieving deep understanding of thermodynamics. Both male and female students of the experimental group outperformed their counterparts of the comparison group as shown in Table 7.4. The conceptual change approach is better than the traditional transmission of information approach in fostering deep understanding and in empowering female students.

Table 7. 4: Means, standard deviations, and n for chemistry test gain as a function of gender and treatment (group)

Group	Males				Females		Total	
	n	M	SD	n	M	SD	M	SD
Experimental	22	12.82	5.47	18	14.33	6.89	13.50	6.11
Comparison	16	1.94	9.77	24	3.21	7.99	2.70	8.65
Total	38	8.24	9.24	42	7.98	9.30	8.10	9.21

The significant F for groups (treatment) means that for the students there is significant difference between genders of the two groups. The females of comparison group are less than females of experimental group on mean chemistry test gain score ($M=3.21$ vs. 14.33). And the males of the two groups did differ significantly ($M=1.94$ vs. 12.82) on chemistry test gain score as well. This shows that both males and females have shown, in the treatment that requires reasoning, argumentation, justification and reflection on chemical thermodynamics content, almost equal achievement on tests.

In conclusion, based on results of the above tables and graphs, the overarching (main) null hypothesis of the study, H_0 , is rejected. And also the null sub-hypothesis, H_{02} , is rejected. In general, the female students of the treatment group performed equally with their male counterparts in understanding grade 12 chemical thermodynamics unit. Most of the extrarational constructs were enhanced for both female students and male students compared to comparison group students. Therefore, the SCSMCC as integrated model of conceptual change has definitely empowered female students in understanding chemistry as a science subject and the model is indeed superior to the traditional transmission of information method in achieving gender equality by empowering female students.

7.5 The Advantage of Conceptual Change Approach in Enhancing the Performance of Low Achievers in Grade 12 Chemical Thermodynamics Unit

The purpose of this section is to show how the conceptual change approach enhances the performance of low achievers compared to the traditional transmission of information method. In this case we use one-way ANOVA or single factor analysis of variance as the factor is a three level factor. The independent variable/factor has nominal or a few ordered levels. The assumptions of ANOVA are: observations or scores are independent, equal variance on the dependent variable across groups, and the dependent variable is normally distributed for each group. We use one-way ANOVA because we have one independent variable/factor which is the ability levels. We can do several one-way ANOVAs at a time using SPSS which we call MANOVA. This analysis is done to study the effects of ability grouping on the academic achievement of Grade 12 students of Bole secondary school in Addis Ababa and which ability level(s) is/are responsive to the treatment of SCSMCC as holistic model of conceptual change which uses the RPC method.

Table 7.5 provides descriptive statistics for the three ability levels/groups on each of the five dependent variables--chemistry test gain, chemistry attitude gain, chemistry motivation gain, chemistry learning strategies perceptions gain and chemistry study skills gain taken for the analysis within the experimental group. Although these five dependent variables appear together in each of the tables, we have really computed five separate one-way ANOVAs. In this table, low achievers have the highest mean in:

chemistry test gain (15.44) and chemistry perception gain (4.78). In the same table, medium achievers have the highest mean in: chemistry attitude gain (1.19). The high achievers have the highest mean in: chemistry study skills gain (11.50) and chemistry motivation gain (16.26). The overall data for the experimental data shows that the order of reception of the new strategy/model was highest in low achievers, average in high achievers and lowest in medium achievers within the experimental group. Even the magnitudes of the gains are small for the comparison group compared to the experimental group as shown in this table. Pintrich and associates (1993) also proposed that high self-efficacy in learning may create confidence in one's ability to engage in change-promoting activities such as argumentation and experimentation which enhance conceptual change. This suggests conceptual change pedagogies such as SCSMCC which uses RPC method should be designed to enhance and facilitate conceptual change. As shown from the data above, resistance to new ideas is low in low achievers, average in high achievers, and lowest in medium achievers. As can be seen from the results above no clear pattern emerge as in Physical Thermodynamics. We can still see that low achievers have shown, in both treatments, that they are highly responsive to the new model of conceptual change. Background knowledge-well established in psychological literature as a facilitator of learning could have affected or increased the degree of changing to new conceptions in Chemical Thermodynamics as well. No clear pattern is observed in the mean gains of the experimental group and comparison group in Table 7.5. Even the magnitudes of the gains for comparison group ability levels are small compared to the experimental group ones as shown in this table.

Table 7. 5 :Means and standard deviations comparing the three ability groups of experimental students

Ability levels	n	Chemistry Test Gain		Chemistry Attitude Gain		Chemistry Motivation Gain		Chemistry Strategies Gain		Chemistry Study Skills Gain	
		M	SD	M	SD	M	SD	M	SD	M	SD
Low achievers	9	15.44	6.95	0.67	15.40	10.00	10.20	4.78	8.60	-2.56	46.38
Medium achievers	21	12.19	6.30	1.19	11.74	11.95	2.61	0.48	6.40	10.43	29.62
High achievers	10	14.50	6.70	1.80	13.99	16.26	5.14	-1.70	4.69	11.50	35.19
Total	40	13.50	6.11	1.23	12.83	10.28	12.60	0.90	6.82	7.78	34.77

Table 7.6, shows that the test of Homogeneity of variables for all the five variables and together with the ANOVA table. The Levene Test is significant for all the variables of both groups. So the variances are not significantly different. This tests an assumption of ANOVA but not of the central hypotheses. The degrees of freedom for both groups is: 2,37. There is no significant between group differences for all the

variables as the table shows for the experimental group and comparison group. For both groups, the assumption of equal variance is not violated. And we should use for all the variables one-way ANOVA, as the overall F is not significant in the ANOVA table of the experimental group. In the comparison group, for 'chemistry motivation gain' ($p=0.000$) and 'chemistry test gain' ($p=0.006$) the overall F is significant and we should use a post hoc test (such as Tukey) designed for situations in which the variances are equal.

Table 7. 6: One-way analysis of variance summary table for experimental group comparing ability levels on the key variables used in the study

Source	df	SS	MS	F	p
Chemistry Test Gain					
Between groups	2	80.04	40.02	1.08	0.352
Within groups	37	1377.96	37.24		
Total	39	1458.00			
Chemistry Attitude Gain					
Between groups	2	6.14	3.07	0.02	0.982
Within groups	37	6414.84	173.37		
Total	39	6420.98			
Chemistry Motivation Gain					
Between groups	2	129.77	64.88	0.40	0.676
Within groups	37	6064.21	163.90		
Total	39	6193.98			
Chemistry Strategies Gain					
Between groups	2	206.71	103.35	2.38	0.11
Within groups	37	1608.89	43.48		
Total	39	1815.60			
Chemistry Study Skills Gain					
Between groups	2	1247.11	623.56	0.50	0.61
Within groups	37	45889.87	1240.27		
Total	39	47136.98			

The ANOVA part of the table is the key part because it shows whether the overall F , for these five ANOVA s, is significant or not. Note that the three ability levels differ significantly on 'chemistry test gain' in both the experimental group and comparison group but not on other variables. $F(2, 37) = 10.23$, $p=0.000$, for chemistry test gain of the comparison group. The 2, 37 are the degrees of freedom (df) for the between groups "effect" and within groups "error" respectively. However, when we have 3 or more groups we may not know which specific pairs of means are statistically different, unless we do a *post hoc* or *a priori* comparison test. In the above we have seen that the overall F for ANOVA is significant only for 'chemistry test gain' of the experimental group and comparison group. We use Tukey HSD (Honestly Significant Differences) test, if the Levene test was not significant or the Games Howell test, if the Levene test was significant. In our case, the Levene test was not significant for both experimental

group and comparison group on chemistry test gains and hence we should use the Tukey *post hoc* test. We should do *post hoc* tests only if the overall F is significant. The one-way ANOVA table helps us in deciding whether to use post hoc multiple comparison tests or not. If the groups are more than two (or two repeated measures) we use either of the above two tests to determine the sources of the differences.

Table 7. 7: Means and standard deviations comparing the three ability groups of comparison students

Ability levels	n	Chemistry Test Gain		Chemistry Attitude Gain		Chemistry Motivation Gain		Chemistry Strategies Gain		Chemistry Study Skills Gain	
		M	SD	M	SD	M	SD	M	SD	M	SD
Low achievers	12	5.50	5.33	-1.67	18.95	5.92	15.13	-16.75	19.02	4.00	35.39
Medium achievers	19	4.63	8.10	3.26	16.62	-9.53	11.29	-8.26	23.14	-10.32	31.52
High achievers	9	-5.11	9.41	7.44	21.59	10.44	11.22	-5.22	24.22	10.44	33.66
Total	40	2.70	8.65	2.73	18.32	-0.40	15.14	-10.13	22.14	-1.35	33.53

Since the overall F is not significant for all variables, which mean differences are significant is not a question. Therefore, no parametric test is required as in Chapter six. We can see that comparing Tables 7.7 with 7.5 above that the magnitudes of the mean gains for experimental groups variables are higher than those of comparison groups variables. This shows that both rational and extra rational constructs are enhanced by the SCSMCC as comprehensive model of conceptual change which uses RPC method for the three ability levels. This makes this model unique compared to models of conceptual change hitherto developed. Tables 7.9 and 7.10 further elaborate the mean differences between ability levels and justify the above statement about the SCSMCC and the accompanying RPC method.

Table 7. 8: One-way analysis of variance summary table for comparison group comparing ability levels on the key variables used in the study

Source	df	SS	MS	F	p
Chemistry Test Gain					
Between groups	2	714.09	354.05	6.00	0.006*
Within groups	37	2202.31	59.52		
Total	39	2916.40			
Chemistry Attitude Gain					
Between groups	2	437.40	218.70	0.64	0.533
Within groups	37	12650.57	341.91		
Total	39	13087.98			
Chemistry Motivation Gain					
Between groups	2	3119.72	1559.86	9.92	0.000*
Within groups	37	5817.88	157.24		
Total	39	8937.60			
Chemistry Strategies Gain					
Between groups	2	808.89	404.44	0.82	0.449
Within groups	37	18311.49	494.91		
Total	39	19120.38			
Chemistry Study Skills Gain					
Between groups	2	3122.77	1561.39	1.42	0.255
Within groups	37	40720.33	1100.55		
Total	39	43843.10			

*The calculated p value is significant at $\alpha=0.01$

Post hoc analysis (from Latin *post hoc* means "after this") in the context of design and analysis of experiments refers to looking at the data--after the experiment has concluded--for patterns that were not specified *a priori*. It is sometimes called *data dredging*, that is, the more one looks into the data, the more likely that something will be found. Post hoc tests are also known as *a posteriori* or *follow up* tests. In this case the three ability levels are unequal in sample size and we should use the harmonic mean instead of the predetermined mean of equal sample size. The mean comparisons from Table 7.6 for the experimental group are statistically significant. The Tukey test requires computation of the so-called studentized range for three or more groups.

Table 7. 9: Post hoc multiple comparisons of chemistry test gain of the comparison group using Tukey HSD test

(I) Ability Levels	(J) Ability Levels	Mean Difference (I-J)	Standard Error	P	95% Confidence Interval	
					Lower Bound	Upper Bound
Low Achievers	Medium Achievers	0.87	2.84	0.950	-6.08	7.81
	High Achievers	10.61	3.40	0.010*	2.31	18.92
Medium Achievers	Low Achievers	-0.87	2.84	0.950	-7.81	6.08
	High Achievers	9.74	3.12	0.010*	2.12	17.37
High Achievers	Low Achievers	-10.61	3.40	0.010*	-18.92	-2.31
	Medium Achievers	-9.74	3.12	0.010*	-17.37	-2.12

**mean differences are significant for high and low; high and medium are significant at $\alpha=0.05$ level*
 The Tukey HSD test is a common post hoc test to use when variances are equal. This table is most appropriate when the group ns are similar. Here they are quite different. The mean difference (i-j) is shown alongside the significance level if the group sizes were similar. I ignored the duplicates in the table and the ANOVA table is repeated here to make matters easier. The second part of the output shows the Tukey HSD test for the ability levels. From Table 7.9, for mean ‘chemistry test gain’, there is a significant ($p=0.010$) mean difference between low achievers and high achievers, and between ‘middle achievers and high achievers (0.010), but there is no significant ($p=0.95$) mean difference between low achievers and middle achievers. For ‘Chemistry motivation gain’, there is a significant ($p=0.005$) mean difference between low achievers and middle achievers and between middle achievers and high achievers ($p=0.001$).

Table 7. 10: Post hoc multiple comparisons of chemistry motivation gain of the comparison group using Tukey HSD test

(I) Ability Levels	(J) Ability Levels	Mean Difference (I-J)	Standard Error	P	95% Confidence Interval	
					Lower Bound	Upper Bound
Low Achievers	Medium Achievers	15.44	4.62	0.005*	4.15	26.73
	High Achievers	-4.53	5.53	0.694	-18.03	8.97
Medium Achievers	Low Achievers	-15.44	4.62	0.005*	-26.73	-4.15
	High Achievers	-19.97	5.07	0.001*	-32.36	-7.58
High Achievers	Low Achievers	4.53	5.53	0.694	-8.97	18.03
	Medium Achievers	19.97	5.07	0.001*	7.58	32.36

**The Mean differences is significant at $\alpha=0.01$ level*
 But there is no significant ($p=0.694$) mean difference between high achievers and low achievers. The Homogeneous subsets table shows an adjusted Tukey that is appropriate when group sizes are not similar

as in this case. Note that there is no statistically significant difference ($p=0.959$) between ability levels in their 'chemistry test gain' of the comparison group. For 'chemistry motivation gain' there is no significant ($p=0.650$) mean difference between ability levels. Similarly, Table 7.11 and 7.9 shows the general trend in both comparison group and experimental group is that the mean gain on 'chemistry test gain' decreases as we move from low to medium, and to high achievers. The comparison group trend in gain is LA=5.50, MA=4.63, and HA=-5.11; the experimental group trend in gains is LA=15.44, MA=12.19, and HA=14.50. The pattern is not the same as that of 'Physical Thermodynamics' for experimental group but magnitudes of results are enhanced in Chemical Thermodynamics for high achievers. The gains are lowest for MAs and highest for LAs (low achievers) but the magnitudes are larger for all groups of the experimental students compared to comparison group students. Table 7.11 shows the means and standard deviations for chemistry test gain separately for the two groups and the three ability levels.

Table 7. 11: Means, standard deviations, and n for chemistry test gain as a function of treatment (group) and ability levels

treatment (group) and ability levels								
Ability Levels	n	Experimental		n	Comparison		Total	
		Group			Group		M	SD
		M	SD		M	SD		
Low Achievers	9	15.44	6.48	12	5.50	5.33	9.53	7.79
Medium Achievers	21	12.19	5.31	19	4.63	8.10	10.28	8.02
High Achievers	10	14.50	4.80	9	-5.11	9.41	-1.15	9.60
Total	40	13.50	6.11	40	2.70	8.65	8.10	9.21

In general, the degree of enhancement of the performance of all achievement levels is higher for experimental group than for the comparison group. And the degree of enhancement of performance of low achievers is higher within the experimental group ability levels as in Physical Thermodynamics. The gain of low achievers of experimental group students is higher than the gain of low achievers of comparison group by 9.94 average gain points. Therefore, the conceptual change approach has an advantage of enhancing the performance of low achievers compared to the traditional transmission of information approach.

Therefore, based on results of the above tables, the overarching or main null hypothesis of the study, H_{01} , is rejected. And also the null sub-hypothesis, H_{03} , is rejected. In general, the low achievers of the treatment group outperformed their comparison group counterparts in understanding grade 12 physical thermodynamics unit. The mean test gain of low achievers is still the highest in chemical thermodynamics as in physical thermodynamics. Most of the extrarational constructs were enhanced for low achievers students compared to comparison group low achievers students. Therefore, the SCSMCC as integrated

model of conceptual change has definitely enhanced the performance of low achievers in experimental group and their understanding of chemical thermodynamic content.

7.6 Prediction of Deep Understanding of Grade 12 Chemical Thermodynamics Unit from a Combination of Motivational Constructs, Treatment and Achievement Levels

Multiple linear regressions use only the participants who have complete data (list wise exclusion) for all the variables in descriptive statistics. The next table shows the output of correlation matrix. The first column shows, for the experimental group, the correlations of the other predictor variables with 'chemistry test gain'. Note that except for 'ability levels' ($p=0.002$), 'chemistry attitude gain' ($p=0.042$), the other variables are not significantly correlated with 'chemistry test gain'. Also notice that all of the variables are negatively correlated, except 'chemistry study skills gain', with 'chemistry test gain' ($r=0.03$). And also notice that the factor 'ability levels' is moderately, negatively, correlated with 'chemistry test gain' ($r=-0.44$), and 'chemistry attitude gain' has small, negative, but significant correlation ($r=-0.28$) with 'chemistry test gain', which is nearly significant ($p=0.068$). 'Chemistry strategies perception, which is not significant ($p=0.108$), gain' has small and negative correlation with 'chemistry test gain' ($r=-0.24$). Gender has small, negative correlation with 'chemistry strategies perception gain' ($r=-0.20$), but not significant ($p=0.108$). Motivational constructs are like double-edged sword in that the valence of the construct can have a positive or negative effect on learning outcome (Pintrich, et al., 1993). Their impact can be towards adopting or resisting a new idea. The negative correlation showed that the higher the ability level the higher the resistance to conceptual change and the lower the ability level, the lower the resistance. High self-efficacy for learning may create confidence in one's ability to engage in change--promoting activities such as argumentation and experimentation. High self-efficacy, however, could also translate into confidence in one's current conception, thus creating intolerance for change (Pintrich, 1999). Research suggests that a tendency to hold on to one's point of view impedes the likelihood of change (Sinatra et al., 2004). The findings of this research somehow confirm the above mentioned researchers ideas and results.

Pintrich and associates (1993) analyzed the role of motivational constructs in facilitating or inhibiting conceptual change and took them as equally important in which they recognized the need to examine the classroom context to fully appreciate how these constructs play out in actual learning situations. Examining classroom context as a facet of the change process was arguably as influential as the focus on motivational constructs. They also argued that the classroom context may influence students' motivation and cognition and most importantly, interaction between these two constructs. The results of this research corroborate their assertion. The **model summary** table shows that the multiple correlation coefficient(R),

using all the predictors simultaneously, is 0.634 and the **adjusted R^2** is 0.294, meaning that 29.4% of the variance in 'chemistry test gain' can be predicted from the combination of the six variables shown in the table. Note that the adjusted R^2 is lower than the unadjusted $R^2=0.402$. This is, in part, related to the number of variables in the equation.

Table 7. 12: Means, standard deviations, and inter-correlations for Chemistry test gain and indicator variables of the experimental group (n=40)

Variable	M	SD	Gender	Ability Levels	Chemistry Attitude Gain	Chemistry Motivation Gain	Chemistry Strategies Gain	Chemistry Study Skills Gain
Chemistry Test Gain	13.50	6.11	-0.13	-0.44**	-0.28*	-0.07	-0.24	0.03
Predictor Variable								
Gender			--	0.01	-0.11	0.11	-0.20	-0.18
Ability Levels			0.01	--	0.05	0.12	-0.07	-0.23
Chemistry Attitude Gain			-0.11	0.05	--	0.15	0.03	-0.12
Chemistry Motivation Gain			0.11	0.12	0.15	--	0.08	-0.06
Chemistry Strategies Gain			-0.20	-0.07	0.03	0.08	--	-0.03
Chemistry Study Skills Gain			-0.18	-0.23	-0.12	-0.06	-0.03	--

** $p=0.002<0.01$; * $p=0.042<0.05$

As you can see from the coefficients Table 7.13, only 'ability levels' as enhanced by 'treatment' is significant ($p=0.002$), but the other variables will always add a little to the prediction of 'chemistry test gain'. Because several independent variables are used, a reduction of the number of variables might help us find an equation that explains more of the variance in the dependent variable, once the correction is made. It is helpful to use the concept of parsimony with multiple regressions, and use the small number of predictors needed. The ANOVA table indicates that $F=3.701$ and is statistically significant ($p=0.006$). This indicates that the combination of these predictors, significantly combine together to predict 'chemistry test gain'.

Table 7. 13: Multiple linear regression analysis summary for key variables used in the study predicting chemistry test gain of the experimental group (n=40)

Variable	B	SEB	β
Constant	110.69	25.04	
Gender	-3.14	1.74	-0.26
Ability Levels	-5.48	1.55	-0.50*
Chemistry Attitude Gain	-0.15	0.07	-0.31**
Chemistry Motivation Gain	0.04	0.07	0.08
Chemistry Strategies Gain	-0.29	0.13	-0.33***
Chemistry Study Skills Gain	-0.03	0.03	-0.17
Note: $R^2 = 0.402$ (Adjusted $R^2 = 0.294$); $F(6, 33) = 3.701, p = 0.006 < 0.01$			
* $p = 0.001$; ** $p = 0.035 < 0.05$; *** $p = 0.024 < 0.05$			

The most important table is the **coefficients** Table 7.13. It shows the **standardized beta coefficients**, which are interpreted much like correlation coefficients. The t value and the sig. (p) opposite each independent variable indicates whether that variable is significantly contributing to the equation for predicting 'chemistry test gain'. Thus, 'ability levels' ($p = 0.001$), chemistry attitude gain ($p = 0.035$), and chemistry learning strategies perceptions gain ($p = 0.024$). The ability levels contributed 44%, chemistry attitude gain contributed 27.6%, and chemistry learning strategies perception gain contributed 24% and the rest are contributed by the other variables (see first column of correlations table). Therefore, if we delete one of the predictors, even if it is not significant, it can affect the levels of significance for other predictors. For example, if we delete 'ability levels', it is quite possible that 'chemistry study skills' would be a significant predictor. The regression shows that 29.4% of the variance in 'chemistry test gain' is explained by the model. According to Cohen (1988) this is somewhere between medium and large effect. Therefore, SCSMCC as comprehensive model of conceptual change and the accompanying RPC method resulted in practically significant changes in knowledge and the other extra rational or "hot" constructs used in the treatment.

In general, the SCSMCC as integrated model of conceptual change turn out to predict the understanding of learners with a high degree of success as 29.4% of the variance is explained by the regression model and which is somewhere between medium and large effect. Therefore, based on results of the above tables, the overarching or main null hypothesis of the study, H_0 , is rejected. And also the null sub-hypothesis, H_{04} , is rejected. And, as a result, the integrated model of conceptual change is superior to the traditional method of transmission of information in achieving deep understanding of chemical thermodynamics content. It can also predict deep understanding successfully as shown by the regression model.

7.7 Conclusions

The results of this chapter have shown that the SCSMCC-based RPC method used for the treatment was effective in fostering deep conceptual understanding of Grade 12 physical thermodynamics unit compared to the traditional transmission of information method. The conceptual change approach developed by integrating individual and social formation of concepts used the two sides of knowledge acquisition as a check and balance for each other and which is evolving in a spiral manner. I used mixed ability and mixed gender groups during small and whole class discussion phases of the SCSMCC and I feel that such careful group formation has resulted in empowering female students and enhanced the performance of low achievers as shown in both Chapter six and Chapter seven. By alternating between group discussion and individual critical thinking in the process of learning, which uses this balanced or symmetrical approach, student can be lead to restructure and change their concepts in a more efficient way. The SCSMCC believes in the power of individual mind in knowledge generation but this should go hand in hand with sharing of information and experience with others. Neither the personal formation of concepts nor the social formation of concepts turns out to be effective when used separately. The results of this chapter support this experimental fact.

The results also showed that experimental variables predicted conceptual understanding of treatment group students with 29.4% of the variance in 'chemistry test gain' is explained by these variables. This is somewhere between medium and large effect. The regression model is, therefore, a significant predictor of conceptual understanding. The results have also shown that the changes in motivation, attitude, and classroom socio-cultural contextual factors were significant in addition to knowledge change. In both treatments of physical thermodynamics and chemical thermodynamics the results mentioned above are found to be consistent which shows that the SCSMCC as symmetrical-integral model of conceptual change is a stable model across contexts in predicting thermodynamics understanding..

CHAPTER EIGHT: THE COMPREHENSIVE MODEL OF CONCEPTUAL CHANGE AND ITS IMPACT ON: CONCEPTUAL KNOWLEDGE, PROCEDURAL KNOWLEDGE AND KNOWLEDGE TRANSFER

8.1 Introduction

In this chapter results of conceptual understanding and procedural understanding in Physical thermodynamics and Chemical Thermodynamics are discussed. Results of knowledge transfer from Physical Thermodynamics to Chemical Thermodynamics for the experimental group will be discussed using paired samples t-test in which some knowledge transfer has been shown. The result of knowledge transfer is not statistically significant but there are changes. This result could be due to conceptual learning without associated procedures in physical thermodynamics unit treatment. I also showed knowledge transfer in various ability levels of the experimental group using GLM repeated measures ANOVA. The knowledge transfer is significant in high achievers, almost constant in medium achievers, and slight change in low achievers. Classroom supervisors' observations are summarized and discussed. Finally, I transcribed and reflected on interviews of student conceptions of thermodynamics after the completion of treatments which is shown in Appendix K. The interview on concepts of thermodynamics was used to see the reason they provide for each conceptual question.

8.2 Checking for Assumptions

The Exploratory Data Analysis (EDA) for conceptual understanding and procedural understanding scores is shown in Table 8.1 with descriptive statistics for normality assumptions. For both procedural understanding and conceptual understanding scores, the skewness statistic values are between -1 and 1. We can, thus assume that they are normally distributed and parametric statistics can be applied in the analysis of data.

8.3 Effect of Conceptual Change Approach on Conceptual Understanding and Procedural understanding of Grade 12 Physical Thermodynamics Unit and Chemical Thermodynamics Unit

We need to balance conceptual knowledge and procedural knowledge in our instruction and assessment at all levels of science education. The term "balance" became popular as educators in many occasions have taken extreme positions on matters of pedagogical importance. Learning both concepts and procedures can enhance proficiency in science and mathematics education. Table 8.1, shows descriptive statistics for the two groups, separately, regarding gain scores of Physical Thermodynamics, conceptual understanding and procedural understanding. The means for the two gain scores of the two groups look different. The mean gain of experimental group's conceptual understanding score is 4.25 and the mean gain of comparison group's conceptual understanding score is 0.88. And the difference between the two

groups is significant ($p=0.001$) and as Levene's test is not significant, equal variance is assumed. Traditionally, rote memorization of procedures with little concern for associated concepts resulted in low conceptual understanding as shown for the comparison group. Similarly, the mean gain of experimental group's procedural understanding score is 6.08 and the mean gain of comparison group's procedural understanding score is 4.28. The t-test was found to be not significant ($p=0.351$). The results for both conceptual understanding and procedural understanding have shown that experimental group taught using constructivist conceptual change strategies outperformed the comparison group taught using the traditional transmission of information method. Therefore, the experimental and comparison groups are significantly different in Physical Thermodynamics conceptual understanding, but they did not have significant difference in procedural understanding even though the procedural understanding of the experimental group is better by 1.80 average points. As the study put emphasis on conceptual understanding, it is not surprising that there were no significant differences in procedural understandings in physical thermodynamics treatment. The mean difference on conceptual understanding gain score between the two groups is 3.38 and the mean difference on procedural understanding gain score between the two groups is 1.80. Regarding practical significance or effect size, $d=0.78$ for conceptual understanding which is nearly large effect and $d=0.21$ for procedural understanding which is a little bit more than small effect, according to Cohen (1988). This could be due to my emphasis on conceptual learning during physical thermodynamics treatment.

Table 8. 1: Comparison between experimental and comparison groups on Physical Thermodynamics conceptual and procedural understandings ($n_{EG}=40$ and $n_{CG}=40$)

Variable	M	SD	MD	t	df	p	Skewness Statistic
Conceptual Understanding Score			3.38	3.503	78	0.001*	-0.287
Experimental Group	4.25	4.02					
Comparison Group	0.88	4.58					
Procedural Understanding Score			1.80	0.939	78	0.351	0.168
Experimental Group	6.08	8.25					
Comparison Group	4.28	8.88					

* $p<0.01$

Grade 12 physics text book emphasizes procedural understanding over associated conceptual understanding. It is therefore more of a traditional text than a constructivist one. In the treatment of physical thermodynamics, even though conceptual knowledge has the power to create its own facts and procedures, the connection between conceptual knowledge and procedural knowledge was not explicit

and the two knowledge categories were not properly balanced because of my emphasis on conceptual knowledge. This affected physical thermodynamics procedural understanding, $d=0.21$, which is a small effect and knowledge transfer from physical thermodynamics to chemical thermodynamics which could have been higher in value. However, conceptual understanding, $d=0.78$, which is nearly a large effect was not affected. Problem solving cannot be efficient unless conceptual understanding is taught with associated procedures. However, in chemical thermodynamics treatment the two knowledge types were somehow balanced than their physical thermodynamics counterparts.

Table 8.2, shows descriptive statistics for the two groups separately regarding gain scores of Chemical Thermodynamics conceptual and procedural understandings. The means for the two gain scores of the two groups look different. The mean gain scores of the experimental group conceptual understanding is 4.05 and the mean gain of comparison group conceptual understanding gain score is 0.90. The results show that the traditional transmission of information method is not helpful in achieving conceptual understanding while the constructivist conceptual change strategies enhanced students' conceptual knowledge. As Levene's test is not significant, equal variance is assumed and the difference between the two groups is statistically significant ($p=0.001$) regarding their conceptual understandings. Similarly, the mean gain of experimental group's procedural understanding score is 9.68 and the mean gain of comparison group's procedural understanding score is 2.70. In chemical thermodynamics treatment, as Grade 12 chemistry text book dictates, I balanced both conceptual and procedural knowledge. And as a result both conceptual and procedural understandings are significantly different for the two groups. Here as Levene's test is significant, equal variance is not assumed and the difference between the two groups is statistically significant ($p=0.000$). Therefore, in Chemical Thermodynamics, the experimental and comparison groups are significantly different in both conceptual and procedural understandings.

Table 8. 2: Comparison between experimental and comparison groups on Chemical Thermodynamics conceptual and procedural understandings ($n_{EG}=40$ and $n_{CG}=40$)

Variable	M	SD	MD	t	df	p	Skewness Statistic
Conceptual Understanding Score			3.15	-4.27	65.556**	0.000*	0.267
Experimental Group	4.05	2.32					
Comparison Group	0.90	3.70					
Procedural Understanding Score			6.98	-6.65	75.779**	0.000*	0.694
Experimental Group	9.68	4.27					
Comparison Group	2.70	5.07					

* $p<0.01$ and **the t and df were adjusted because variances were not equal

The mean difference on conceptual understanding gain score between the two groups is 3.15 and the mean difference on procedural understanding gain score between the two groups is 6.98. Regarding practical significance, effect size, $d=0.77$ for conceptual understanding which is nearly large effect and $d=1.12$ for procedural understanding which is more than large effect, according to Cohen (1988). Procedural knowledge that is over-practiced without conceptual knowledge are often forgotten or remembered incorrectly. On the other hand, conceptual knowledge without fluency in procedural knowledge can inhibit the problem-solving process (Bossè and Bahr, 2008). Proficiency in science depends on both procedural knowledge and conceptual knowledge. Science learning at all Grade levels requires understanding of procedures, concepts and processes. Science is a web of interrelated concepts and procedures and therefore we need to understand both. Learning concepts before procedures may help students to understand the procedures but when they learn procedures before concepts they may not learn underlying concepts.

Figure 8.1, compares the pre-test and post-test mean physics conceptual understandings between experimental group and comparison group total scores. Tables 8.1 and 8.2 compare the two groups using their mean gain scores. Figures 8.1 to 8.4 complement the tables by providing mean total scores of the two groups. The graphs show that there are almost no differences in the mean pre-test total scores. The initial difference in test between the two groups is -0.40 on a scale of 27 in Physical Thermodynamics achievement test. The final difference between the two groups on mean post-test scores is 2.98 on a scale of 27 in Physical Thermodynamics achievement test, which is a significant difference. Both the mean total score comparisons using graphs and the mean gain score comparisons using tables corroborate that there is a significant difference between the two groups regarding Physical Thermodynamics achievement.

Constructivist conceptual change strategies such as RPC based on SCSMCC which apply an instructional sequence which begins with a problem task and which invites solving a problem in multiple ways by way of sharing, justifying and discussing in small or large group discourses can usually balance conceptual knowledge and procedural knowledge. This strategy is like CAPs strategies from which my RPC was developed to implement my SCSMCC as integrated model of conceptual change. The results shown in Figures 8.1 to 8.5 and in Tables 8.1 and 8.2 corroborate that conceptual change strategy was more effective than traditional strategy in enhancing and balancing conceptual knowledge and procedural knowledge. SCSMCC is a symmetrical-balanced approach itself which promotes balance between: conceptual knowledge and procedural knowledge as well as individual and social formation of concepts.

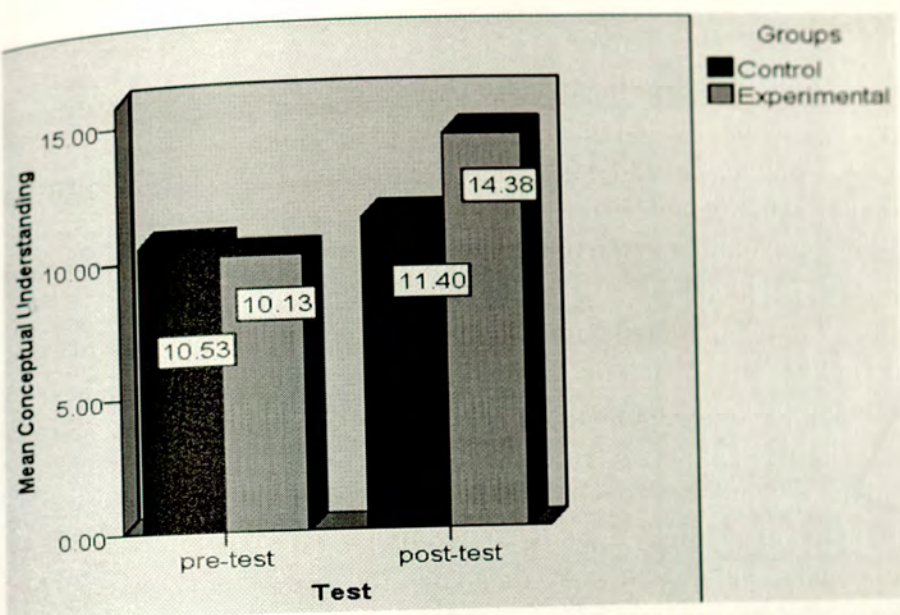


Figure 8. 1: Mean difference in physics conceptual understandings between experimental and comparison groups

Figure 8.2, shows the mean difference in physics procedural understandings between experimental group and comparison group total scores. The initial difference between the two groups is 1.80 on a scale of 27. The final difference between the two groups on mean post-test total scores is 3.60 on a scale of 27. The total difference between the test scores is 1.80 which is not a significant difference. Both the mean total score comparisons using graphs and the mean gain score comparisons using tables corroborate that there is no significant difference between the two groups regarding their procedural understanding of physics. The constructivist sequence shown in SCSMCC can be used to promote both conceptual learning and procedural learning. Procedural fluency and conceptual understanding should be developed through problem solving, reasoning, and argumentation as shown in CAPs strategies used in this research. Methods of assessment must change concomitantly with curricular changes. The traditional assessment practices in science tend to reward speed and accuracy in recalling facts and procedures without understanding the complex underlying concepts. Therefore, a balance between conceptual learning and procedural learning should go hand in hand with a balance of the type of assessment used to capture that learning. Procedural knowledge and conceptual knowledge may not be the only types of learning which should be balanced, but they are always the major ones.

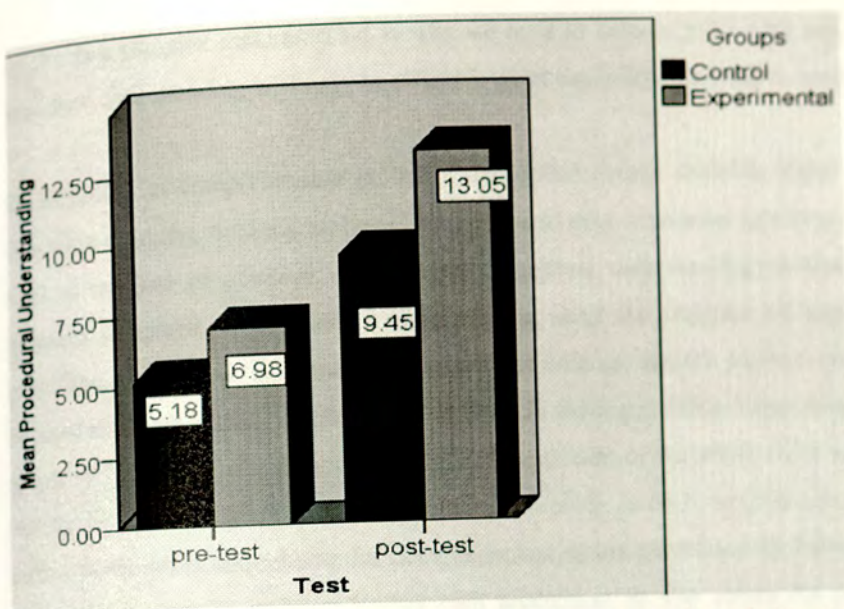


Figure 8.2: Mean difference in physics procedural understandings between experimental and comparison groups

Figure 8.3, shows the mean difference in chemistry conceptual understandings between experimental group and comparison group total scores. The initial difference between the two groups is -0.23 on a scale of 27 regarding their mean pre-test scores. The final difference between the two groups is 1.90 on a scale of 27 regarding their mean post-test scores. The total difference between the two groups is 2.13 on the same scale. The total difference between test scores using both graphs and the mean gain score comparisons using tables corroborate that there is a significant difference between the two groups regarding chemistry conceptual understandings. In our conceptual change strategies, a problem task is understood as a situation for which neither the result nor the method of solution is known where as exercise is a task or a situation in which result is unknown but a method of solution is known. In phase six of SCSMCC, students have to demonstrate their deep understanding of concepts and procedures using problems but not exercises. Exercises are solved using procedural understanding but problems are solved using conceptual understanding and associated procedures. Procedural knowledge should always complement conceptual knowledge for effective physical science learning. If a model such as SCSMCC focuses on exercises rather than problems as tasks, then it will lead to algorithmic efficiency and accuracy which is simply rediscovering the old wheel. Conceptual understanding should lead to the efficiency of memory but not vice versa. Rote memorization is one way of unlearning procedures and concepts. Mostly conceptual understanding should be related to deep understanding, but only with associated procedural knowledge. Conceptual knowledge cannot exist without procedural knowledge as science subjects mix

the two in a complex manner. That is why we need to balance procedural and conceptual knowledge. Procedural understanding will only be effective when explicitly connected to conceptual understanding.

The SCSMCC as comprehensive model of conceptual change demands higher metacognitive thinking than lower cognitive thinking abilities. We know that only conceptual problems have no *a priori* known result or method of solution. Therefore, conceptual understanding involves higher psychological processes compared to procedural understanding. And the sequence of teaching the two types of knowledge types look as though conceptual knowledge should precede procedural knowledge. A balanced approach such as SCSMCC should help in solving problems rather than doing only exercises in normative science which cannot help in the development of the whole child who is an asset but not a liability for the society. Our curriculum should provide carefully crafted conceptual problems for the science fields rather than asking for doing exercises whose procedures are known. Conceptual problems require the student to develop his/her own procedures as s/he solves the problems based on deep understanding of the concepts involved. The current curriculum provides exercises but not problems and therefore it is simply reinventing the old wheel.

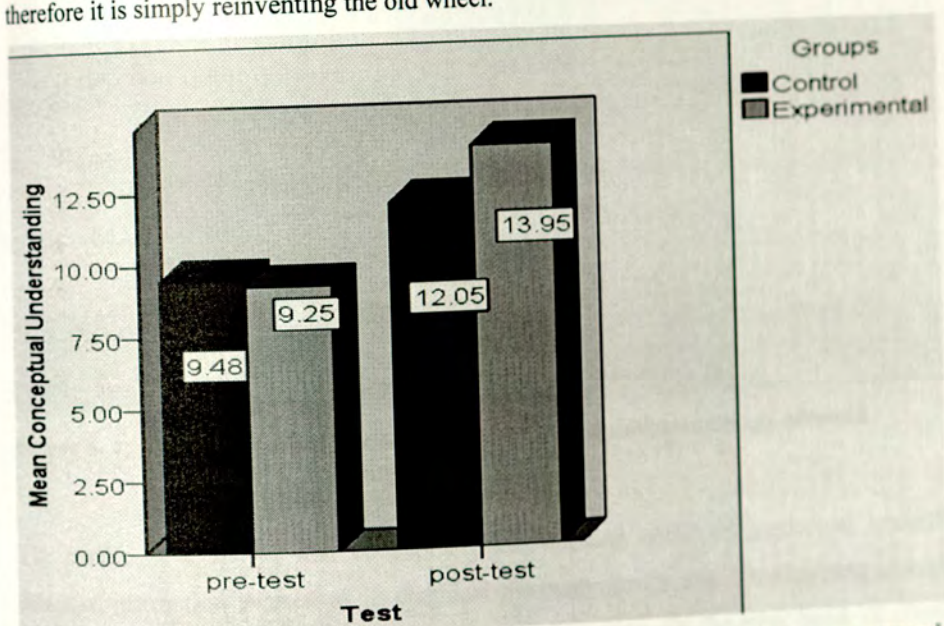


Figure 8. 3: Mean difference in chemistry conceptual understandings between experimental and comparison groups

Figure 8.4, shows mean difference in chemistry procedural understandings between experimental and comparison groups total scores. The initial difference between the two groups is -0.67 on a scale of 27 regarding their mean pre-test scores. The final difference between the two groups is 6.98 on the same scale regarding their mean post-test scores. The total difference between test scores using both graphs and

the mean gain score comparisons using tables corroborate that there is a significant difference between the two groups regarding chemistry conceptual understandings.

Constructivist conceptual change strategies such as RPC based on SCSMCC can balance procedural and conceptual knowledge in either instruction or assessment while traditional strategies create imbalance by emphasizing procedural knowledge over conceptual knowledge. Traditional assessment and instruction emphasize the importance of speed and accuracy during tests. In conceptual change strategies enough time should be given for students to explicate conceptual knowledge by way of reasoning, argument, and justification. That is why phase six of SCSMCC as integrated model of conceptual change took about 10 minutes of the classroom period to solve conceptual problems with associated procedural knowledge.

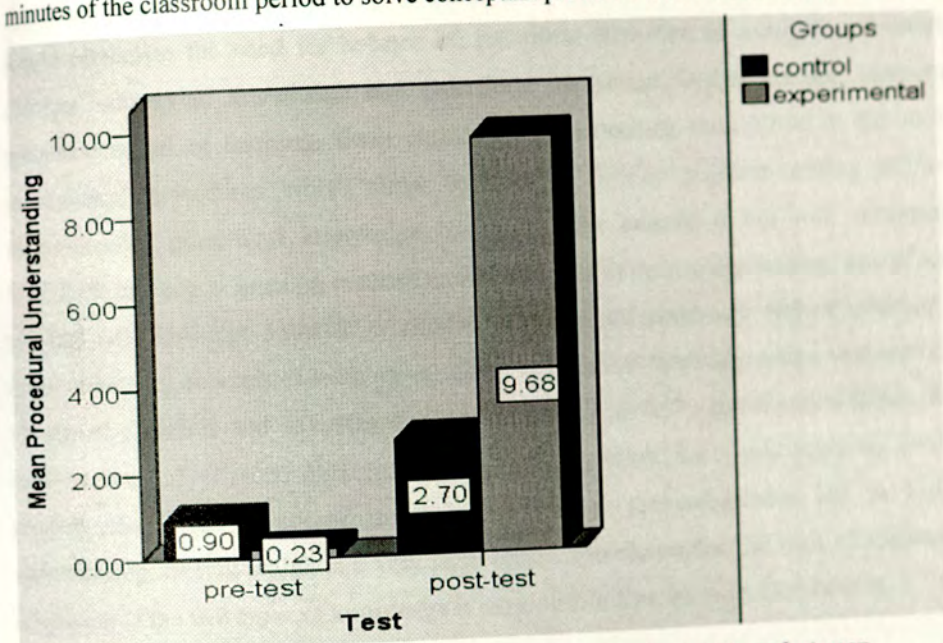


Figure 8. 4: Mean difference in chemistry procedural understandings between experimental and comparison groups

The results have shown that conceptual understanding enhanced procedural understanding when a balanced instruction is used as in chemical thermodynamics unit. Emphasizing procedural knowledge over conceptual knowledge is a traditional way of teaching. On the other hand, emphasizing conceptual knowledge without a proper balance with associated procedures would lead to a situation similar to physical thermodynamics treatment in which conceptual knowledge cannot enhance procedural knowledge. Therefore, it is better to promote the balance of the two types of knowledge than emphasizing one over the other.

Teachers must be educated and trained based on the belief of balanced conceptual and procedural knowledge in order for them to apply constructivist strategies such as RPC based on SCSMCC in fruitful manner. This is one way of keeping standards and by doing so we can produce scientists and engineers which can solve problems using their creativity and innovation. We should make the connections between procedural and conceptual knowledge explicit, in addition to, balancing the two types of knowledge so that we can enhance the long term retention of both (Schoenfeld, 1988). The issue of balancing instruction with assessment; conceptual knowledge with procedural knowledge; and individual construction of knowledge with social construction of knowledge depicted by SCSMCC as integrated model of conceptual change in Figure 1.1 of chapter one, is more fundamental than we ever thought. The SCSMCC rejects any imbalance or asymmetry in either instruction or assessment. Our objectives of instruction should emphasize the need for balance of: individual formation of concepts and social formation of concepts, conceptual knowledge and procedural knowledge, instruction and assessment, etc. in a symmetric model of learning. Deep conceptual understanding should lead to the ability to perform mathematical procedures which allow students to develop problem solving skills. We need to reconceptualize procedural knowledge in light of the balance it has with conceptual knowledge. Traditional procedural learning resulted in students' lack of deep understanding, lack of solving problems and lack of knowledge transfer to similar situations. Of course, procedural practice has led to no improvements in conceptual learning as shown in chemical thermodynamics treatment as the text book has lots of exercises and as conceptual understanding, $d=0.77$ is not very different from conceptual understanding of physical thermodynamics, $d=0.78$ where there was relatively limited procedural practice. But, the procedural practice in chemical thermodynamics led to higher procedural understanding, $d=1.12$ which is a very large effect. This shows that the issue of sequence and balanced integration of the two types of knowledge is more serious than we have ever thought.

In conclusion, the overarching or main null hypothesis of this research, H_0 , is rejected. And also the null sub-hypothesis H_{05} , is rejected. The SCSMCC as integrated model of conceptual change is more effective in achieving deep conceptual understanding and deep procedural understanding than the traditional method of transmission of information. The integrated model of conceptual change had a significant effect on conceptual understanding and procedural understanding of secondary school Grade 12 physical science learners.

8.4 The Conceptual Change Approach and the Issue of Knowledge Transfer

We can easily transfer knowledge from everyday situations to the classroom context, but it is very difficult to transfer school science to real world context. The asymmetry in the direction of knowledge transfer may be due to counter-intuitive nature of scientific theories. This asymmetry of knowledge

transfer cannot be explained by the cognitive or sociocultural/situative perspective separately, but it can be explained by the conceptual change approach to learning. The SCSMCC as a symmetrical and balanced approach works towards a situation in which there is a balance and symmetry in knowledge transfer from everyday situations to the classroom context and from the classroom to real world contexts. School knowledge is different in structure, explanatory framework, etc. from everyday experience and the culture of the society but by requiring students to individually and socially learn in a balanced manner we can create a situation in which a symmetrical transfer of knowledge between classroom and real socio-cultural setting would occur. Transferring school knowledge to real world contexts requires considerable knowledge reorganization which is difficult to achieve traditionally but which can be achieved using conceptual change models such as SCSMCC as integrated model of conceptual change. Everyday knowledge when transferred to school science knowledge causes misconceptions as it competes for learner's conceptual space and these misconceptions can be overcome by the conceptual change approach to learning. The deep understanding created by the conceptual change approach to learning would allow us to transfer our knowledge to real world contexts. Negative transfer is created when the existing everyday knowledge becomes a barrier to understanding scientific knowledge. The other problem is lack of understanding of school knowledge which creates difficulty of knowledge transfer to real world contexts. Both of these situations can be overcome by my SCSMCC as a comprehensive model of conceptual change. In order for the conceptual change approach to address the issue of asymmetry in knowledge transfer, we need to narrow the gap between the cognitive and sociocultural/situative perspectives by making some necessary modification which can bridge the two perspectives. The spiral that acts like a bridge between the two perspectives is designed in SCSMCC to create deep understanding of school knowledge, thereby increasing the possibility of knowledge transfer to real world situations. Initial re-organization of knowledge in 'Initial Personal Thinking' phase of the SCSMCC can help overcome the barrier created by negative transfer or existing everyday knowledge to science learning. In this research a horizontal transfer of physical thermodynamics concepts to chemical thermodynamics is tested in addition to research on conceptual change, a transfer to a slightly different context in school setting. This paves the way for further research on the difficult problem of knowledge transfer to real world contexts. In the following I compare the transfer of learning from Physical Thermodynamics to Chemical Thermodynamics in a time interval of one month.

8.4.1 Comparisons of the Average Gain Scores of Experimental Group Students in Physical Thermodynamics and Chemical Thermodynamics Treatments

Table 8.3 shows the mean for: chemistry and physics test gains; chemistry and physics attitude gains; chemistry and physics learning strategies gains; and chemistry and physics motivation gains; chemistry and physics study skills gains. This means will be compared in the paired samples t-test table. In addition,

the ns(sample sizes), (SDs) standard deviations, and standard errors are shown. The paired samples correlations table shows, the correlations of 'chemistry and physics' attitude gains which is -0.474 and which is highly significant correlations ($p=0.002$). This correlation is a net average negative correlation. This correlation indicates the attitude of students who had had average positive gain in physics had average negative gain in chemistry. Table 8.3 compares the gain scores of pairs of key variables used in physical thermodynamics and chemical thermodynamics treatments. It tries to look into transfer of knowledge, attitude, motivation, perception of learning strategies, and study skills.

Table 8. 3: Comparison between experimental group students gain on pairs of key variables used in physical thermodynamics and chemical thermodynamics ($n_{EG}=40$)

Paired Variables	M	SD	Correlation	MD	SDMD	p
Pair 1 Chemistry Test Gain	13.50	6.11	0.034	3.18	11.54	0.836
Physics Test Gain	10.33	10.00				
Pair 2 Chemistry Attitude Gain	1.23	12.83	-0.474	-6.88	28.41	0.002*
Physics Attitude Gain	8.10	19.98				
Pair 3 Chemistry Motivation Gain	10.28	12.60	0.051	2.13	19.01	0.756
Physics Motivation Gain	8.15	14.89				
Pair 4 Chemistry Strategies Gain	0.90	6.82	0.137	-2.88	12.70	0.399
Physics Strategies Gain	3.78	11.68				
Pair 5 Chemistry Study Skills Gain	7.78	34.77	-0.043	-0.48	44.93	0.794
Physics Study Skills Gain	8.25	27.02				

* $p<0.01$; the only significant change is that of scientific attitude

The paired samples t-test shows that the mean differences of paired variables are not significant for all paired variables. This table shows that the mean difference between chemistry test gain and physics test gain is 3.18, even though there is no significant difference, the mean increased from 10.33 to 13.50 as we move from 'physical thermodynamics' to 'chemical thermodynamics', which shows that there is a limited amount of knowledge transfer. This could be due to conceptual learning without associated procedures in physical thermodynamics unit treatment. If both units of thermodynamics were taught using conceptual knowledge with associated procedures, then the results would have been much better than the one we have here. The attitude gain decreased by a factor of -6.88 in chemical thermodynamics. This can be explained by the fact that conceptual learning without associated procedures in physical thermodynamics resulted in negative attitude in subsequent learning. The chemistry motivation was increased by 2.13. The chemistry perception of strategies was decreased by -2.88. And chemistry study skills decreased by -0.48.

Only the test and motivation have shown an increase in chemistry gains in comparison to physics gains. Therefore, knowledge and motivation have transferred from physics to chemistry. Pintrich and associates (1993:168) noted that "the actual classroom context may influence students' motivation and cognition and most importantly, interaction between these two constructs. Classroom context is as influential as motivational constructs in the process of knowledge restructuring". The result of learning transfer, reported above, corroborate their assertion. According to these authors, a broader view of the learner is one in which cognitive and motivational constructs operate in interaction in the study of knowledge restructuring. The classroom/social context, learner curiosity and students' dissatisfaction with existing conceptions were used as motivators in the process of knowledge restructuring.

8.4.2 Comparison of Means of Test Gain Scores for Various Ability Levels of the Experimental Group Using Repeated Measures ANOVA

In table 8.4, the mean of 'low achievers' for physics test gain is 19.11, the mean of 'medium achievers' for physics test gain is 10.52, and the mean of 'high achievers' for 'physics test gain' is 2.00. The mean of 'low achievers' for 'chemistry test gain' is 15.44, which is lower than their mean for 'physics test gain'. The mean of 'medium achievers' for 'chemistry test gain' is 12.19, which is slightly higher than their 'physics test gain'. The mean of 'high achievers' for 'chemistry test gain' is 14.50 which is significantly higher than their 'physics test gain'. The mean physics gain scores for the three ability levels are highly variable with an interval of almost eight points between pairs of ability levels. The mean chemistry gain scores for the three ability levels are less variable with an approximate interval of one or two points between pairs of ability levels. This could be due to the fact that the SCSMCC as integrated model of conceptual change was strictly applied in chemical thermodynamics than in preceding physical thermodynamics treatment, specifically, regarding procedural knowledge.

Table 8. 4: Means and standard deviations comparing the three ability groups of experimental students in their chemistry and physics test gains

Ability Levels	Chemistry Test Gain			Physics Test Gain		
	n	M	SD	n	M	SD
Low Achievers	9	15.44	5.27	9	19.11	7.30
Medium Achievers	21	12.19	5.65	21	10.52	2.09
High Achievers	10	14.50	8.20	10	2.00	6.45
Total	40	13.50	6.11	40	10.33	10.00

Mauchly's Test of Sphericity was conducted to test the assumption that each of the time periods is approximately equally correlated with every other score. This test is found to be significant ($p=0.000$).

which means that the test scores are correlated. But, while the main effect of tests is not significant ($p=0.180$), the interaction effects of tests and ability levels is highly significant ($p=0.000$). The partial η^2 for the main test effect accounts for nearly 5% of the variability in gain scores when tests are repeated in an interval of one month on similar content of thermodynamics. And the partial η^2 for the interaction effect of tests and ability levels accounts for nearly 56% of the variability in gain scores, which shows significant correlation, when the tests are repeated in an interval of one month.

Table 8. 5: Comparison of the ability levels of experimental group students gain on chemistry and physics test gains using GLM repeated measures ANOVA (within subject)

Source	df	SS	MS	F	p	Partial η^2	Observed Power ^a
Tests	1	58.20	58.20	1.87	0.180	0.048	0.265
Tests * Ability Levels	2	1446.73	723.37	23.23	0.000*	0.557	1.000
Error	37	1152.15	31.14				

^a Computed using $\alpha=0.05$

* $p<0.0001$

The observed power is based on the assumption that the true difference in population means is the difference implied by the sample means. Typically, we want to calculate power going into an experiment based on anticipated or previous effect size in other similar studies. This is useful in making decisions about sample size. In quasi-experiments in which the issue of sample size is not that much necessary, observed power calculated here is not particularly useful.

Table 8. 6: Comparison of the ability levels of experimental group students gain on chemistry and physics test gain using GLM repeated measures ANOVA (between subject)

Source	df	SS	MS	F	p	Partial η^2	Observed Power ^a
Intercept	1	11258.39	11258.39	318.75	0.000*	0.896	1.000
Ability Levels	2	1453.02	726.51	20.57	0.000*	0.526	1.000
Error	37	1306.87	35.32				

^a Computed using $\alpha=0.05$

* $p<0.0001$

Low achievers gain decreased almost by a factor of three, middle achievers gain is increased almost by a factor of one and high achievers increased almost by a factor of 12. The overall change in test gain is about 3.17, which confirms the result of paired samples t-test. Low achievers have gained higher, medium achievers has shown a slight gain, and high achievers have shown a significant increase in their gains. Therefore, learning transfer has occurred significantly in high achievers, but not in medium achievers

which is almost constant. Low achievers have shown a very small non-significant learning transfer. Classroom contextual factors can influence both cognition and motivation which can either facilitate or hinder conceptual change. The problem is to find out how motivation and cognition interact in complex ways to produce knowledge change in addition to how they themselves are affected. The SCSMCC model and the accompanying RPC method has shown that motivational constructs, in addition, to enhancing knowledge change they themselves can be affected and changed.

Therefore, the overarching or main null hypothesis, H_0 , is rejected. And also the null sub-hypothesis, H_{0a} , is rejected. The SCSMCC as comprehensive model of conceptual change had transferred knowledge and motivation from physical thermodynamics to chemical thermodynamics because of the deep understanding it had created. The holistic model of conceptual change has, somehow, shown a good effect on knowledge and motivational constructs transfers from physical thermodynamics to chemical thermodynamics in school setting.

8.5 Validation of Treatments Using Supervisors' Classroom Observations

The supervisors received copies of lessons and observation protocol (check list) formats just after they were trained on the aims of SCSMCC, RPC method and art of scoring an observation checklist. In physical thermodynamics 10 lesson plans and in chemical thermodynamics 12 lesson plans were supervised during the treatments. The physics classes were handled by a teacher in his early 30 years of age and holds M.Sc degree in physics with six years of service. The chemistry classes were handled by a teacher in her early 40s of age and had B.Sc. degree in chemistry, a former lab school student, and were M.Sc. student in 1980 E.C. at Addis Ababa University but did not complete her M.Sc. studies for some reason and had more than 25 years of teaching experience. The copies of lesson plans for the treatment group were given to both teachers regarding the two units they were teaching. The supervisors were selected from the school and were physics and chemistry teachers. The physics teachers were assigned to observe physics classes and the chemistry teachers were assigned to observe chemistry classes.

8.5.1 Supervisors' Observation of Grade 12 Physical Thermodynamics Experimental Classes

Most of the supervisors for the treatment of physical thermodynamics unit identified the purposes of the lessons based on times spent in lessons as focusing on facts, concepts and procedures. They also observed that mostly facts and concepts precede procedures (processes). Regarding the design of the lesson, the supervisors rated the lessons as very good. The lessons were: interactive, reflected careful planning and organization, reflected attention to student experience, preparedness, prior knowledge, learning styles, used cooperative learning or collaborative approach and provided time and structure for "sense-making"

and wrap-up by applying their knowledge to problems which resemble real world contexts. The supporting evidence for this synthesis rating was that the teacher implemented the lessons meticulously in the classes according to the design. It was a short and precise approach and was compatible with the SCSMCC model and accompanying RPC method. Constructivist approach of developing/constructing knowledge by the students was applied. Both personal constructions and social constructions were observed.

The contents and contexts of science match developmental level of students, teacher provision of content information was accurate, students were engaged, elements of science abstraction such as symbolic representations and theory building were used and the degrees of "sense-making" of science content were appropriate to the developmental levels/needs of students. All the supervisors rated on the average that the learning of the contents of physical thermodynamics was very good. The supporting evidence for this synthesis rating was that the contents were in line with international standard, the teacher demonstrated a good understanding of thermodynamics concepts, students were interested to learn and apply concepts of thermodynamics. Start-up activities were done well, and related to learners' everyday experience. The criteria for international standards include: accuracy and up-to-datedness of data, figures, diagrams and content; recent best practices which suit given context; recognition of achievement of others; applications of equal content standards across nations, etc. were used. Students attentively learned after start-up activities. The content was well-developed except for some inaccuracies and misconceptions.

Classroom culture reflected active participation, climate of respect, collegial working relationships reflected in interactions, collaborative working relationships reflected in interactions between students' and teacher, students were encouraged to generate ideas and questions, and intellectual rigor, constructive criticisms and challenging ideas were evident throughout the implementation of the lessons. The supporting evidence for such classroom culture to exist was that students were engaged, collaborated, reasoned, argued, and took a stand as well as solved problems to check their conceptual restructuring and conceptual change. The supervisors' rated the classroom culture as very good on the average.

The supervisors also observed that the students were heterogeneous, with a mixture of two or more ability levels. On the average, the supervisors' agreed that most of the time was spent on instructional activities and only a small amount of time was spent on non-instructional activities. Almost 20 minutes of the total time (40 times) was spent on individual engagement, small group discussion, and whole class discussion. Teacher elaboration of concepts and procedures/processes and students' application of knowledge to solving problems took another 20 minutes.

Regarding the overall ratings of the lessons, the supervisors' agreed that the lessons' had a positive effect on the following areas: Students' understanding of science was enriched by reasoning, argumentation, sharing of information, and application of knowledge to real world context; students understood important science/thermodynamics concepts; they develop confidence in investigating science by their own with little expert guidance; students learned how to apply concepts to other disciplines and/or real-life situations, and students developed appreciation for the science of thermodynamics. Therefore, regarding the likely effect of lessons on students understanding of thermodynamics, the supervisors rated overall the lessons as having a positive effect. In Table 8.1, experimental group students had mean conceptual understanding of 4.25 while the comparison group students had mean of 0.90. In the same table, experimental group students had mean procedural understanding of 6.08 while the comparison group students had mean of 4.28. The SCSMCC as comprehensive model of conceptual change and the accompanying RPC method of critical analysis and reflection were appreciated by the supervisors as a good model and method of teaching science respectively. Students differentiated scientific and non-scientific knowledge using this model and accompanying method. And also students situated or related their knowledge to real-life situations. They were comfortable when taught with SCSMCC as integrated model of conceptual change and accompanying RPC method. Sub-strategies such as small group discussion, individual critical thinking and reflection, and whole class discussion increases students' conceptual understanding.

8.5.2 Supervisors' Observation of Grade 12 Chemical Thermodynamics Experimental Classes

The supervisors of chemical thermodynamics classes, based on the time spent, agreed that the focus of the lessons was equally working on facts, vocabulary, procedures and science concepts. The design of the lessons was based on: tasks, roles, interactions, careful planning and organization, strategies and activities reflected attention to students' experience, preparedness, prior knowledge, learning styles, cooperative learning, and collaborative approach to learning among students, adequate time and structure for "sense-making" and wrap-up, and applications to problems of real-life situations. Most of the supervisors rated the design as appropriate to a great extent. The supporting evidence for this synthesis rating is that the teacher was very serious in implementing the lessons, and enriched the SCSMCC as integrated model of conceptual change and accompanying RPC method using her long years of experience in teaching secondary school chemistry. She implemented the lessons as meticulously planned and used the time effectively. She prepared herself and knows the subject matter very well.

Regarding the implementations of the lessons, the teacher was confident in teaching chemical thermodynamics, instructional strategies were consistent with investigative science, even though they

were occasional classroom disciplinary problems, she managed to control the class. She paced the lessons consistent with the developmental levels/needs of the students and the purpose of the lessons. Instructions were adjusted according to the level of understanding of students, questioning strategies enhanced the development of student conceptual understanding and problem solving, identified prior conceptions and misconceptions and taught ways of overcoming the misconceptions. The constructivist conceptual change method helped in rectifying students understanding problems. The synthesis rating of the implementation was very good. The supporting evidence for this synthesis rating was that the teacher was knowledgeable both in subject matter and pedagogy of science teaching and had willingness to implement the SCSMCC as comprehensive model of conceptual change and the accompanying RPC method.

The supervisors noted that the teaching of chemical thermodynamics topics was contextualized and was also abstract and she tried to adjust science content to the developmental level of students. Teacher provision of content information was accurate, students were engaged with important focal ideas of the lessons and the teacher displayed a good understanding of thermodynamics concepts. Students deconstructed and reconstructed thermodynamics content as a body of knowledge but had not taken it as a finished product. Elements of science abstraction such as symbolic representation, theory building, and the difference in learning analytical and empirical laws were used. Important connections to other disciplines and real-world contexts were made. The extents of "sense-making" of thermodynamics content were appropriate to the developmental levels and needs of students and the purpose of the lessons.

The synthesis rating of chemical thermodynamics content used was on the average good. The supporting evidence for synthesis rating was that I prepared a list of common misconceptions and conceptions of chemical thermodynamics content and gave it to the teacher along with the lesson plans. For each lesson, two categories of parallel misconceptions and valid conceptions were provided onto which students had to take positions as to which category is the scientifically valid category. The students debated, reasoned, argued and took positions and finally reached consensus. The students never took the contents for granted or as a finished product but critically analyzed, reflected upon, and formed deep understanding of the concepts and procedures by applying the knowledge gained to problems which resemble real-world situations. Students, for example, made sense of warming effect on the metal case of a bicycle pump. Students learned the content very well after start-up activities.

The classroom culture reflected active participation, there was a climate of respect for students' ideas, questions and contributions, and interactions reflected collegial working relationships among students. There was a collaborative working relationship between the teacher and students. Teacher encouraged the

students to generate ideas, questions, conjectures, and/or propositions. Intellectual rigor, constructive criticisms and the challenging of ideas were all evident. The rating of the above key indicators, on the average had shown that the classroom culture was very good. The supporting evidence for this synthesis rating was that the teacher implemented the SCSMCC as holistic model of conceptual change and accompanying RPC method just as planned. There was a careful planning and preparation for the lessons and she was able to control the class. She was very serious and motivated in teaching the students and this also contributed to the kind of classroom culture the supervisors had witnessed.

As to lesson arrangements and activities, most of the time was spent on instructional activities and very small amount of time was spent on non-instructional activities. Individual engagement, small group discussion, and whole class discussion took about 20 minutes. The time spent on teacher elaboration of concepts, individual critical reflection, and deep understanding through application of knowledge took another 20 minutes. There was no major interruption encountered in the teaching of the thermodynamics unit. The overall rating of the lesson regarding the likely effect of the lessons on students understanding of chemical thermodynamics was quite good and the effect was positive. In Table 8.2, experimental group students had mean conceptual understanding of 4.05 while the comparison group students had mean of 0.90. In the same table, experimental group students had mean procedural understanding of 9.68 while the comparison group students had mean of 2.70. The SCSMCC model as integrated model of conceptual change and RPC method instructions had a positive effect on students' understanding of chemical thermodynamics. The supervisors commented that the students learn science better when they participate in teaching-learning process. And it was also found out that individual critical thinking and reflection, small group discussion, and whole class discussion increased learner confidence. Constructivist conceptual change teaching methodologies are found to be suitable for learning science.

8.6 Student Conceptions of Thermodynamics after Treatment

Interviews were conducted to assess students' post-treatment conceptions and misconceptions of thermodynamics. After the treatments, I selected five grade 12 students at Bole secondary and preparatory school to interview them about their conception of key thermodynamics concepts. Two students were selected from the experimental group (S_4 and S_5) and another two students were selected from the comparison group (S_1 and S_2) and student S_3 was selected from a section outside the two groups. Students were selected with the help of their classroom teachers based on their performance and assumed to be equivalent in their abilities. The experimental group students answered almost 60% of the questions. The comparison group students answered almost 30% of the questions and the one outside the two sections/groups answered about 20% of the questions. I organized their response to similar questions in Appendix K.

The students have almost clear conceptions of heat and temperature. Experimental group students have better conceptions regarding content that heat can be added or removed at constant temperature. They also understood that in quasi-static process, such as isothermal process, there is no temperature change as heat is added or removed. Experimental group students have clear conception regarding heat as a process quantity. In adiabatic process, temperature will increase during compression and only two students, one from comparison(S_2) and one from experimental(S_4) tried to reason out based on the first law of thermodynamics. The same students (S_2 and S_4) reasoned out correctly conditions under which work can be positive, negative, or zero. Except student S_4 , all of the students have correctly answered entropy changes during phase changes. Entropy increases as a substance undergoes changes from solid to liquid to gas and decreases as a substance undergoes changes from gas to liquid to solid. Generally, students have better understanding of second law of thermodynamics compared to the first law of thermodynamics. Only student S_5 argued that wood and metal have the same temperature in the same environment. Most of the students agreed that it is easier to learn chemical thermodynamics than physical thermodynamics. They also said that concepts learned in physical thermodynamics helped them better understand same concepts in chemical thermodynamics. Some students, for example, student S_1 aired lack of horizontal integration in the use of symbols for the same formula and this created some sort of confusion and wasted their time which could have been used to learn other concepts.

All of the five students had difficulty in correctly defining enthalpy. This could be due to, as student S_4 noted, lack of instruction about enthalpy in physical thermodynamics (see context of the research section in chapter three about this topic). Except student S_1 , the other students have difficulty in correctly distinguishing internal energy (U), work (W), and heat (Q) as process or state functions. And only student S_4 attempted to correctly define the term internal energy (U) while others have only partial answers for it.

The results of interview have shown that in all questions related to concepts of the first law of thermodynamics students had misconceptions even after conceptual change strategy is applied to experimental group students. Even in this case, the experimental group students were better than the other students from comparison group and other sections. The first law of thermodynamics is the most misconceived law compared to other laws in thermodynamics. Another most difficult concept for the students was enthalpy. Students were not taught about enthalpy in physical thermodynamics and found it difficult to apply it to Hess's law in chemical reactions in order to distinguish exothermic and endothermic reactions.

8.7 Conclusions

The conceptual change approach has shown its effectiveness in bringing about deep conceptual understanding. The effect size for physical thermodynamics conceptual test achievement is 0.78 and the effect size for chemical thermodynamics conceptual test is 0.77. These are large effect sizes and the fact that both treatments have similar effect sizes shows that the SCSMCC as integrated model of conceptual change is stable and invariant across contexts. Similar conclusion has been reached after comparing results of Chapters six and seven. Conceptual knowledge and procedural knowledge should be balanced and their connection should be made explicit in any science instruction and assessment. The SCSMCC as a symmetrical conceptual change model itself can balance procedural knowledge and conceptual knowledge, individual and social efforts in learning, instruction and assessment, etc. for deep understanding and effective problem solving. It was found out that there was some knowledge transfer from physical thermodynamics to chemical thermodynamics. This shows that the SCSMCC model had adequately addressed the difficult problem of knowledge transfer compared to the cognitive and situative/sociocultural perspectives. The SCSMCC as holistic and symmetrical model of conceptual change had tackled the problem of asymmetry of knowledge transfer between classroom and real world. Therefore, constructivist conceptual change strategies are better than traditional transmission of information methods in fostering both conceptual understanding with associated procedures and knowledge transfer. Supervisors of both physical thermodynamics and chemical thermodynamics have confirmed that the treatments were conducted as planned, which increase the validity of the results obtained in this research. There is lack of coordination between chemistry and physics authors of text books in using symbols and defining concepts. There are some author-induced misconceptions especially in physics text book. There are errors here and there in both physics and chemistry text books which demand revision of all curricular materials. There is no clear sequence or balance among factual, conceptual and procedural knowledge's in both units of thermodynamics. The issue of appropriate sequence for factual, procedural, and conceptual knowledge requires further investigation. But, the SCSMCC tried to balance conceptual and procedural knowledge for complete understanding of thermodynamics. Conceptually, the first law of thermodynamics and enthalpy are found to be the most difficult topics for students.

CHAPTER NINE: MAJOR FINDINGS, CONCLUSIONS, IMPLICATIONS AND RECOMMENDATIONS

9.1 Introduction

In this chapter, I will report major findings of the research results from chapters six and seven for Grade 12 'Physical Thermodynamics' and 'Chemical Thermodynamics' units treatments, respectively, using the tests of the overarching or main null hypothesis (H_0) and the four other null sub-hypotheses (H_{01} , H_{02} , H_{03} , and H_{04}) by the non-equivalent quasi-experimental design. I will also report results from chapter eight regarding the testing of the overarching or main null hypothesis (H_0) and the two other null sub-hypotheses (H_{05} , and H_{06}) by the non-equivalent quasi-experimental design. Physical Thermodynamics treatment results are shown in detail in chapter six and Chemical Thermodynamics treatment results are shown in detail in chapter seven. Chapters six and seven share the same four null sub-hypotheses, in addition to, the overarching or main null hypotheses as the treatment is repeated to test the same set of hypotheses in two closely similar contexts in the school setting. In chapter eight, conceptual and procedural understandings for both chemistry and physics units, the problem of knowledge transfer from physics to chemistry, interviews about current status of secondary science curriculum and interview results, after treatment, for selected questions in thermodynamics in order to assess the impact of SCSMCC on students' conceptions are all summarized and reported here in this chapter. And this will be followed by conclusions, implications of the SCSMCC as the integrated model of conceptual change for curriculum design and development and recommendations for future research.

9.2 Major Findings of the Research

In the following, the tests of the overarching or main null hypothesis (H_0) and the six other null sub-hypotheses (H_{01} , H_{02} , H_{03} , H_{04} , H_{05} , and H_{06}) by the non-equivalent quasi-experimental design are reported. The first four null sub-hypotheses and the overarching null hypothesis were tested using the design results of chapters six and seven and the overarching null hypothesis and the last two null sub-hypotheses were tested using the design results from chapter eight.

9.2.1 Major Findings from Physical Thermodynamics and Chemical Thermodynamics Treatments

The null hypotheses found in chapter one are reproduced here to help the reader not to wander for finding the exact statements of the null hypothesis.

The overarching or main null hypothesis of the study is; H_0 : *The integrated model of conceptual change based on critical analytic method is not more effective in achieving deep understanding than the traditional method of transmission of information.*

H_{01} : *The treatment group will not learn thermodynamics more than the comparison group.*

Independent samples t-test for physical thermodynamics treatment shows that experimental group students were significantly different from comparison group students on: physics test gain ($p=0.029$), physics attitude gain ($p=0.029$), and physics motivation gain ($p=0.032$). The effect size(d) of physics test gain is 0.50, for physics attitude gain the effect size (d) is 0.51 and for physics motivation gain the effect size (d) is 0.49, in all the above three cases the effect size d when it is around 0.50 is typical (medium) effect size according to Cohen (1988). Pintrich and his associates (1993) brought a broader view of the learner, one in which cognitive and extra rational constructs operate in a dynamically interacting way in the study of knowledge restructuring. They called for the development of a comprehensive model of conceptual change after they criticized the classical Posner and his associates (1982) model of conceptual change. The SCSMCC is one such response to their call as an integrated model of conceptual change. The students were clearly motivated and had positive attitude towards physics as a result of application of this new model. Experimental group did not differ significantly from comparison group on the average physics perception of learning strategies gain score ($p=0.518$), and on the average physics study skills gain score ($p=0.211$). Therefore, the SCSMCC helped experimental group students to learn physical thermodynamics better than the comparison group students who were instructed using the classical transmission of information method and it was able to create deep understanding of physical thermodynamics concepts and caused changes of motivation and attitude.

Similarly, the independent samples t-test for 'Chemical Thermodynamics' treatment shows that experimental group students were significantly different from comparison group students on: chemistry test gain ($p=0.000$), chemistry motivation gain ($p=0.001$), and chemistry learning strategies perceptions gain ($p=0.004$). The students had been motivated and had positive perceptions towards the new model and method. But there are no significant differences on: chemistry attitude gain ($p=0.673$) and chemistry study skills gain (0.236). The trend in motivational constructs is sometimes unpredictable and the result of physical thermodynamics shows that attitude was positive and significant and in chemical thermodynamics the change in attitude was insignificant. The change in attitude had increased in the first treatment and became almost constant in the second treatment. The effect sizes (ds) for: chemistry test gain is 1.44 which is an extremely large effect; chemistry motivation gain is 0.77 which is a large, more than typical effect; chemistry perception gain is 0.69 which is somewhere between medium and large effect; and chemistry study skills is 1.63 which is an extremely large effect. Therefore, the SCSMCC helped experimental group students to learn chemical thermodynamics better than the comparison group students who were instructed using the classical transmission of information method and it was able to create deep understanding of chemical thermodynamics concepts and caused changes of motivation,

perceptions of learning strategies, and study skills. And, therefore, H_0 is rejected in both physical thermodynamics and chemical thermodynamics contexts.

Therefore, in both physical thermodynamics and chemical thermodynamics cases, the SCSMCC and the accompanying RPC method have shown significant and large effects on students' understanding of thermodynamics. In both contexts the new integrated conceptual change model is found to be a valid one in fostering deep understanding.

H_{02} : *Female students in the experimental group will not be empowered by the treatment more than those in the comparison group.*

Two-tailed t-test is not significant for all the variables ($P_s > 0.05$) and hence there is no significant difference between boys and girls of physical thermodynamics experimental group. This means that the new integrated conceptual change model empowered the female students to the level of male students. Similar t-test for the comparison group has shown that there are no gender differences in all variables mean gains except for 'Physics learning strategies perceptions variable' ($p = 0.01 < 0.05$) which is significant. The comparison group female students at least do believe that the traditional transmission of information model was not treating them equally with male students during instruction.

Similarly, the two-tailed t-test is not significant for all the variables ($P_s > 0.05$) and hence there are no significant difference between boys and girls within the chemical thermodynamics' experimental group. This means that the new conceptual change model empowered the female students to the level of male students. For the comparison group there are no significant gender differences in all variables except for 'Chemistry learning strategies perceptions gain' variable ($p = 0.034 < 0.05$) which is significant. In both cases there are gender differences in the comparison group regarding learning strategies perceptions which could be due to classroom socio-cultural contextual factors which were not adequately addressed by the traditional lecture demonstration method. This shows that classroom contextual factors have empowered the girls in experimental group which have shown similar perceptions as the boys. Therefore, H_{02} is rejected and SCSMCC as integrated model of conceptual change has empowered female students in learning both physical thermodynamics and chemical thermodynamics.

H_{03} : *The performance of low achiever students in the experimental group will not be enhanced by the treatment more than the low achievers in the comparison group.*

For the experimental group, the low achievers have the highest mean in: physics test gain, 19.11; physics motivation gain, 12.67' and physics learning strategies gain, 5.33. Medium achievers have the highest

mean in: physics attitude gain, 12.33 and physics study skills gain, 14.10. The high achievers have almost the lowest mean gain in all variables. This could be due to high-self efficacy of the high achievers which resulted in holding on to own conceptions. The order of reception of the new RPC strategy and SCSMCC is highest in low achievers, average in medium achievers, and lowest in high achievers. No such pattern is observed in the mean gains of the comparison group. Even the magnitudes of the gains in all variables are small compared to the experimental group. This shows that the new conceptual change approach has enhanced the performance of low achievers compared to medium achievers and high achievers in majority of variables including understanding of physical thermodynamics concepts.

The Levene test is significant for 'physics learning strategies gain' ($p=0.005$) of experimental group and for 'physics study skills gain' ($p=0.006$) of the comparison group, so these variables are significantly different. This tests an assumption of ANOVA but not of the central hypotheses. The between group differences for 'physics test gain' is the only significant gain ($p<0.05$) for both the experimental and the comparison groups. For the 'Physics learning strategies perception gain' ($p=0.005$) of the experimental group and for 'Physics study skills gain' ($p=0.006$) of the comparison group, the assumption of equal variance is violated and we should use for the two cases the similar non-parametric test, the Kruskal-Wallis test, since the overall F is not significant (if the overall F were significant we could have used a post hoc test (such as Tukey) designed for situations in which the variances are unequal). In the ANOVA table (chapter six), note that the three ability levels differ significantly on 'physics test gain' for both the experimental and comparison groups but not on other variables. $F(2,37)=10.10.23$; $p=0.000$, for physics test gain of the experimental group and $F(2,37)=5.69$; $p=0.007$ for physics test gain of the comparison group. For 'physics test gain', the Tukey table indicates that there is a significant difference between 'low achievers' and 'medium achievers' and 'low achievers' and 'high achievers' but there is no significant difference between 'medium achievers' and 'high achievers' of the comparison group ($p=0.488>0.05$).

A statistically significant difference was found among the three ability levels of the experimental group on 'physics test gain'. The means for physics test gain score of experimental group are : for high achievers is 2.00, for medium achievers is 10.52, and for low achievers is 19.11. And the mean 'physics test gain' score of comparison group: for high achievers is -1.44; for medium achievers is 3.18; and for low achievers is 11.79. This shows that there are 7.32 average points difference between experimental and comparison groups low achievers. The new model enhanced the performance of low achievers better than the traditional transmission of information method. Post hoc Tukey HSD Tests indicate that the three ability levels differed significantly in their 'physics test gain score' for the experimental group ($P<0.05$).

And post hoc Tukey HSD Tests indicate that the three ability levels differed significantly in their 'physics test gain score' for low and medium, and low and high but not for medium and high achievers of the comparison group.

In 'Chemical Thermodynamics' treatment, a statistically significant difference was found among the three ability levels on 'chemistry test gain', $F(2,37)=6.00$; $p=0.006$ and for 'chemistry motivation gain', $F(2,37)=9.92$; $p=0.000$, of the comparison group the overall F is significant and we should use a post hoc test (such as Tukey) for these variables which is designed for situations in which the variances are equal. The mean 'chemistry test gain' score of experimental group: for low achievers are 15.44, for medium achievers is 12.19, and for high achievers is 14.50. And the mean 'chemistry test gain' of comparison group: for low achievers is 5.50, for medium achievers is 4.63, and for high achievers is -5.11. Note all the signs (+ or -) but also the magnitudes are quite different between experimental group and comparison group. Post hoc Tukey test indicate that the three ability levels differ significantly between low and high, middle and high, but not between low and middle ($p=0.95>0.05$) in 'chemistry test gain'. Similarly, Tukey test indicate that there is a significant difference among the three ability levels, namely, low and middle, and high, except between high and low achievers regarding 'chemistry motivation gain'. Here there is significant difference between low achievers of experimental groups and low achievers of comparison group by 9.94 average points which is extremely significant. Overall we can say that, in both physical thermodynamics and chemical thermodynamics contexts, the new holistic conceptual change approach is significantly better than traditional approach in enhancing the performance of low achievers. Therefore, H_{03} is rejected and the SCSMCC as integrated model of conceptual change had enhanced the performance of low achievers more than the traditional method.

H₀₄: The integrated model of conceptual change cannot predict deep understanding more than the traditional model of transmission of knowledge.

Simultaneous multiple regression was conducted to investigate the best predictors of 'physics test gain' scores. When the combination of variables to predict 'physics test gain' included all of the six variables, $F(6,33) = 3.66$; $p=0.007<0.01$. Note that 'ability levels' enhanced by the treatment and the 'constant' term are the only variables which significantly predict 'physics test gain', in addition to treatment when all the six variables are included. The adjusted R squared value was 0.290. This indicates that 29% of the variance in 'physics test gain' was explained by the multiple regressions model. According to Cohen (1988), this is somewhere between medium and large effect.

Similarly, simultaneously multiple regression was conducted to investigate the best predictors of 'chemistry test gain' scores. When the combination of variables to predict 'chemistry test gain' included

all of the six variables, $F(6,33) = 3.70$; $p=0.006<0.01$. Note that 'the constant term' ($p= 0.000$), the 'ability levels' ($p= 0.001$), in addition to treatment, 'chemistry learning strategies perceptions gain' ($p= 0.024$), and 'chemistry attitude gain' ($p= 0.035$) are the variables which significantly predicted 'chemistry test gain' when all the six variables are included. The adjusted R squared value was 0.294. This indicates that 29.4% of the variance in 'chemistry test gain' was explained by the multiple regressions model. According to Cohen (1988) this is, again, between medium and large effect. Both physics test gain and chemistry test gain are predicted for the experimental group and in both cases the multiple regressions model explained about 29.4 % of the variance. According to Cohen (1988) the effect of rational and extra rational constructs on conceptual change and knowledge restructuring is somewhere between medium and large effect. This shows that SCSMCC as holistic model of conceptual change and the accompanying RPC method are indeed valid in fostering conceptual change and knowledge restructuring. Therefore, the variables used in the treatment have shown best predictive power of students' understanding of thermodynamics in both physical thermodynamics and chemical thermodynamics contexts with utter consistency. The new integrated model of conceptual change which I have tested, shows context independence or invariance and stability across contexts which again show that the new model is indeed a comprehensive model of conceptual change.

Therefore, based on the above results, the overarching null hypothesis of the study, H_a , is rejected. And also all the first four null sub-hypotheses are rejected. The results show that the integrated model of conceptual change and its accompanying RPC method is more effective than the traditional transmission of information method and students learn thermodynamics better in SCSMCC-based RPC method than in traditional transmission of information method. The SCSMCC empowered female students, enhanced the performance of low achievers, and successfully predicted deep understanding of thermodynamics in both physics and chemistry contexts.

9.2.2 Major Findings on Conceptual Understanding, Procedural Understanding, and Knowledge Transfer

H_{05} : *The integrated model of conceptual change has no effect on conceptual and procedural understandings more than the traditional model of transmission of knowledge.*

Experimental group students were significantly different from comparison group on 'physical thermodynamics' conceptual understanding ($p=0.001$) and on procedural understanding the experimental group students were not significantly different ($p= 0.351$) from comparison students. This could be due to my emphasis on conceptual knowledge more than procedural knowledge during this treatment. The teacher who conducted physical thermodynamics treatment might not offered conceptual explanations for procedures. Many teachers who followed their education in Ethiopia have been taught by the traditional

transmission of information method and most of them have a good mastery of procedural knowledge than conceptual knowledge. Inspection of the two group means showed that the average conceptual understanding gain score for comparison group, 0.88, is significantly lower than the conceptual understanding gain score, 4.25, for experimental group. The difference between the means is 3.38 on a 27-point conceptual test scale. Similarly, the average procedural understanding gain score for comparison group, 4.28, is not significantly lower than the experimental group average procedural gain score, 6.08. The mean difference between the means is 1.80 on the 27-point procedural test scale.

The experimental group students were significantly different from comparison group students on both 'Chemical Thermodynamics' conceptual understanding ($p = 0.001$) and procedural understanding ($p = 0.000$). Inspection of the two groups means show that the average conceptual understanding gain score for comparison group, 0.90, is significantly lower than the average conceptual understanding gain score, 4.05, for experimental group. Similarly, the average procedural understanding gain score for comparison group, 1.80, is significantly lower than the average procedural understanding gain score, 9.45, for the experimental group. The effect size (d) of 'Physical Thermodynamics' conceptual understanding is 0.78, which is found to be a large effect. And the effect size for procedural understanding is 0.21, which is a small effect for 'Physical Thermodynamics'. Similarly, the effect size for 'Chemical Thermodynamics' conceptual understanding is 0.77, which is again found to be a large effect, and the effect size for 'Chemical Thermodynamics' procedural understanding is 1.12 which is more than a large effect. Therefore, except for 'Physical Thermodynamics' procedural understanding which has a small effect, in both cases conceptual understanding has shown a large effect. For chemistry treatment, procedural understanding has shown a more than large effect which can be attributed to lots of numerical calculations in the units' activities, exercises and examples compared to physics treatment. The conceptual and procedural knowledge is more balanced in chemistry treatment than in physics treatment.

The conceptual understanding effect size for physical thermodynamics ($d=0.78$) and the effect size for chemical thermodynamics conceptual understanding ($d=0.77$) are almost the same and constant. This shows the context independence of the model and procedural exercises in chemical thermodynamics contributed to procedural understanding but did not affect chemical thermodynamics conceptual understanding. In both physics and chemistry cases, conceptual understanding of the treatment group is significantly higher than that of the comparison group and the effect sizes are large. This shows that the SCSMCC is really a valid integrated model of conceptual change and knowledge acquisition. Therefore, H_{05} is rejected and the integrated model of conceptual change can enhance both conceptual and procedural understandings when implemented meticulously.

H₀₆: The holistic model of conceptual change has no effect on knowledge and extra rational constructs transfers in school setting.

The paired samples correlations table showed the correlations of 'chemistry and physics' attitude gains which is -0.474 and the correlation between the two gains is highly significant. This correlation indicates that the attitude of students, who had average positive gain in physics, had average negative gain in chemistry. The paired samples t-test showed that the means of the paired variables are not significant ($P_s > 0.05$) for all paired variables. The above mentioned table showed that the mean difference between chemistry test gain and physics test gain is 3.18. Even though there is no significant ($P_s > 0.05$) difference, the mean increased from 10.33 in physics to 13.50 in chemistry. This shows that there is a limited amount of knowledge transfer. Only the chemistry test and chemistry motivation have shown an increase compared to all physics gains. When comparing chemistry and physics treatments in both paired samples t-test and repeated measures ANOVA, the only non-significant positive gains are those of tests and motivations. The only significant variable between treatments which has shown negative gain is science attitude. Therefore, the cognitive and motivational factors are the only variables which have shown signs of positive horizontal transfer. This means that there are both positive knowledge and motivation transfer from physics to chemistry but attitude has shown a negative transfer. Negative affect is related to resistance to new conceptions when applied to new situations.

The reason for negative affect could be due to background attitude of physics which was significant and medium in effect size meaning the practical significance was not as high as we expected, contributing to the decline of this construct in chemistry. There were no changes in classroom socio-cultural contextual factors as the learning strategy and model used were the same. The SCSMCC as comprehensive model of conceptual change is, therefore, better than other models of conceptual change hitherto developed in addressing the difficult problem of knowledge and extra rational constructs transfer. If it were not for my emphasis on conceptual knowledge in physical thermodynamics, the results would have been better than the one reported here. Therefore, the overarching or main null hypothesis, **H₀**, is rejected. And also the null sub-hypothesis, **H₀₆**, is rejected. The SCSMCC as comprehensive model of conceptual change had transferred knowledge and motivation from physical thermodynamics to chemical thermodynamics because of the deep understanding it had created. The holistic model of conceptual change has, somehow, shown a good positive effect on knowledge and motivational constructs transfers from physical thermodynamics to chemical thermodynamics in school setting.

9.2.3 Validation of Treatments

The physics supervisors identified the purposes of the lessons based on times spent in lessons as focusing on facts, concepts and procedures. They also observed that mostly facts and concepts precede procedures or processes. They rated the designs of the lessons, on the average as 'very good'. According to them, the lessons were: interactive, reflected careful planning and organization, reflected attention to students' experience, preparedness, and prior knowledge, learning styles, used cooperative/collaborative learning, provided time and structure for "sense-making" and wrap-up by applying their knowledge to problems which resemble real world contexts. The supporting evidence for this synthesis rating was that the teacher meticulously implemented the design. It was a short and precise approach and was compatible with the SCSMCC integrated model and accompanying RPC method. In addition, the contents of science match developmental level of students, teacher's provision of content information was accurate, students were engaged, and elements of science abstraction such as symbolic representations and theory building were used.

All the supervisors rated, on the average, that the learning of the contents of 'Physical Thermodynamics' was "very good". The supporting evidence for this synthesis rating was that the teacher demonstrated a good understanding of thermodynamics concepts, start-up activities are done well and related to students' everyday experience. The content was well-developed except for some inaccuracies and misconceptions. The classroom culture reflect active participation, climate of respect and collegial working relationships reflected in interactions, students were encouraged to generate ideas and questions, intellectual rigor, constructive criticism and challenging ideas were evident throughout the implementation of the lessons. The supporting evidence for such classroom culture to exist was that students were engaged, collaborated, reasoned, argued, and took a stand/position and solved problems to check their conceptual restructuring and conceptual change. The supervisors rated, on the average, the classroom culture as 'very good'. The supervisors also observed that the students were heterogeneous with a mixture of two or more ability levels. On the average, as supervisors agreed, most of the time was spent on active participation of learners in instructional activities. Almost 20 minutes of the total of 40 minutes were spent on individual engagement, small group discussion, and whole class discussion. Teacher elaboration, students' critical reflection and application of knowledge gained to solving problems took another 20 minutes. The supervisors concluded that, in their overall ratings of lessons, the lessons had a positive effect on the: students' understanding of thermodynamics which was enriched by reasoning, argumentation, sharing of information, application of knowledge to real world contexts and through critical reflection.

The design of lessons include: tasks, roles, interactions, careful planning, organization, strategies and activities reflected attention given to students' experience, preparedness, prior knowledge, learning styles, cooperative/collaborative approach to learning among students, adequate time and structure for 'sense-making' and wrap-up and application to problems of real life situations. The design was rated, on the average, as appropriate to 'a greater extent'. The supporting evidence for this synthesis rating is that the teacher was very serious in implementing the design, and enriched the SCSMCC as integrated model of conceptual change and RPC method using long years of experience and higher qualifications in teaching secondary school Physics. He implemented the lessons as planned meticulously and used the time effectively. The pace of the lessons was consistent with the developmental level of students and adjusted to the level of understanding of students. Questioning strategies enhanced students' conceptual understanding, problem solving, identified prior conceptions/misconceptions and used to teach ways of overcoming the misconceptions. The synthesis rating of the implementation, on the average, was "very good". The supporting evidence for this synthesis rating was that the teacher was knowledgeable both in subject matter and pedagogy of science teaching and had willingness to implement the SCSMCC comprehensive model and accompanying RPC method.

The synthesis rating of 'Chemical Thermodynamics' content used was, on the average, 'very good'. The supporting evidence for this synthesis rating was that the teacher used the two categories of valid and invalid conceptions to initiate student thinking, group discussion, and whole class discussion, and allowed the class to come to a consensus. The students debated, reasoned, argued and took positions. The students were asked not to take the content for granted or as a finished product but critically analyzed, reflected upon, and formed deep understanding of the concepts and procedures by applying knowledge gained to real-world situations. The classroom culture reflected active participation, climate of respect for students' ideas, questions, contributions and interactions showed collegial working relationships among students as well as with the teacher. Teacher encouraged the students to generate ideas, questions, conjectures, and or propositions. Intellectual rigor, constructive criticism and the challenging of ideas were all evident. The synthesis rating of the above key indicators, on the average, showed that the classroom culture was 'very good'. The supporting evidence for this synthesis rating was that the teacher implemented the SCSMCC holistic model and accompanying RPC method just as planned. Students had a good deal of respect of their teacher as she was very serious in teaching them and this contributed to the synthesis rating of the supervisors.

Documentary analysis and interviews were used in chapters three and eight. Unit one of Grade 12 physics and unit three of grade 12 chemistry were page by page analyzed. Here, the content evaluation summary

for unit one of Grade 12 physics and unit three of Grade 12 chemistry will be made and based on the evaluation suggest whether the units require major or minor revisions. In addition, the evaluation of curriculum guides and teacher guides on those units will help us determine whether the curriculum is constructivist or not and also interviews with chemistry and physics curriculum experts help us determine the status of the current curriculum. After the treatment, I interviewed five students on some concepts of thermodynamics to see if the students have really understood thermodynamics. Students S_4 and S_5 were from the experimental group students S_1 and S_2 were from the comparison group and student S_3 was from another section in which thermodynamics was taught.

In Physical Thermodynamics text book, the authors defined 'caloric' as 18th century conception of heat which was "an invisible, mass less fluid running 'downhill'". On page nine, however, some mention of heat as a substance was made. "A substance has mass; some students think heat as a transfer of substance." The authors did not distinguish between the caloric ($m=0$) and heat as a substance ($m\neq 0$), even though both were wrong. Sufficient explanation should be given about the nature of heat. On page 11, it is conceptually wrong to write the first law as $\Delta U = \Delta W + \Delta Q$. This gives the impression that Q and W are state functions while they are process functions. It must be written as $\Delta U = W + Q$, where for process quantities we must not use Δ as the authors did in the above. The symbol Δ is used to show difference between two values of state (point) functions. Author(s) induced misconceptions last longer as most students are not critical about what they learn.

In page 12, for isothermal process ($\Delta T=0$, but not $Q=0$) and for adiabatic process ($Q=0$, but not $\Delta T=0$), the concept of heat reservoir was not used. If it were used for isothermal process $\Delta T=0$, but not exactly zero; for adiabatic process $Q\approx 0$, but not exactly zero concepts would have been discussed. The situation is more idealized than made realistic. On the curriculum guide (CG) and the teacher guide (TG) the resources mentioned in them were not sufficient and available in the school in order to develop lessons in the text and bring about conceptual change. The methods presented in TG and CG are: lecture, discovery learning, discussion, questioning, problem solving, demonstration, etc. The methods are not purely constructivist as demanded in the text book (see pp.6-7 of Grade 12 Teacher's Guide). Therefore, the so-called constructivist curriculum was not implemented as intended. The authors wrote the equation for enthalpy as $\Delta Q_p = \Delta U + P\Delta V$ at $P=\text{constant}$ and was not labeled it with the name **enthalpy**. The proper symbol for enthalpy is H . $\Delta H = \Delta U + P\Delta V$ is change in enthalpy and is the right equation. Factual, grammatical, computational, and obsolete information are rare in the materials. But errors in illustrations, diagrams, figures, etc. are there. In figure 1.2, the space between hot molecules should have been a little bit apart. In page three, figure caption does not match the figure and also on page 45 (figure 1.42) that is,

converting all the heat to work is forbidden by the second law of thermodynamics but there must have been a thin arrow downward from “hot” to “cold” reservoir.

Unlike Grade 12 physical thermodynamics unit, the authors of ‘Chemical Thermodynamics’ unit related it to Grade 11 chemical kinetics. Unlike in ‘Physical Thermodynamics’, ‘Chemical Thermodynamics’ unit did give duration (Δt) required for thermodynamic processes. The phrase ‘process function’ was used in physics but in chemistry the phrase ‘path function’ replaced it causing confusion in the usage of terms and phrases which shows lack of horizontal coordination among authors of text books. Isothermal processes were explained in relation to heat reservoir (heat bath), which were not explained in similar way in ‘Physical Thermodynamics’. The internal energy’s symbol is U in ‘Physical Thermodynamics’, but its symbol is E in ‘Chemical Thermodynamics’ which confuses the students. In thermodynamics, the internal energy is the total energy contained by a thermodynamic system. Excludes any external energy supplied to the system and it is the energy needed to create the system. It is the sum of kinetic and potential energies. The internal energy can be changed by heating or doing work on a system. As a hot system is cooled it does work on the surrounding. For isolated system internal energy cannot change, such as the universe; it is an intrinsic energy to a system. The concept of internal energy is not coherently discussed.

In chemistry, the state function nature of internal energy is more explicit than in physics text as $\Delta E = E_{\text{final}} - E_{\text{initial}}$. The authors of chemical thermodynamics unit were very cautious when writing the first law of thermodynamics; they did not use Δ (delta) for W and Q which was the major source of misconceptions in many thermodynamics books. Here, the authors also provided sign conventions which they gave for both Q and W . See Table 3.2 for ‘content evaluation summary’ in chapter three. Teaching strategies were more explicit here than in physical thermodynamics unit. They ask students to form groups, discuss, write a short report, and present to a class, even though it lacked variety. On page 130, they correctly defined enthalpy (H) as heat absorbed or released at $P=\text{constant}$. In general, the chemical thermodynamics unit is better written than physical thermodynamics unit. However, the quantitative/procedural knowledge is a little bit overdone compared to conceptual knowledge.

In CG, teaching methods, learning activities and evaluation measures were congruent with learning objectives unlike in physics unit. Resources mentioned in the CG were sufficient and mostly available in the school for developing lessons. In TG, the teaching methods were: gapped lectures, cooperative/collaborative learning, group discussion, presentation, demonstration, experiments, concept mapping, questioning, spider diagram, visualization, brainstorming, etc. were assumed to be used but there is no match with textbook methods. Not all methods used, as in physical thermodynamics, were constructivist methods. For example, gapped lectures and demonstrations are teacher-centered based on

traditional behaviorist methods of knowledge transfer not as the curriculum experts at MoE and authors of books have claimed.

Interviews were conducted to assess students' current conceptions and misconceptions of thermodynamics and to assess current status of secondary science curriculum. Both the chemistry expert (E_1) and physics expert (E_2) gave their views on selected questions I forwarded to them. Both E_1 and E_2 mentioned that they determine the content based on minimum learning competencies. They both responded that the purpose of secondary science curriculum is derived from ETP (1994). They both reasoned that the best learning theory for science curriculum is the constructivist learning theory and it is better than traditional behaviorist/cognitivist learning theories. The strategies used, according to them, are active-learning/constructivist strategies. They reasoned that continuous and terminal assessments are used in evaluation. They responded, also that, the resources are not uniformly available across schools. They said that they have tried to integrate factual, procedural, and conceptual understandings. But made no mention of whether they are balanced or not. They said, also that, the current science curriculum is constructivist and has the power to overcome students' misconceptions and learning difficulties.

Students from experimental group have almost correctly answered 60% of the 11 questions. Students from the comparison group answered 30% of the 11 questions and another student from outside the two sections answered about 20% of the questions. You can see the details of the responses in the last pages of chapter eight. The interview has clearly shown that students of similar ability grouping have different conceptions of thermodynamics after the treatment and the experimental group students have better conception than comparison group students. In all questions asked about concepts related to the first law of thermodynamics, the first law is the most misconceived law compared to other laws in thermodynamics. The concepts of enthalpy, determining whether a reaction is endothermic or exothermic reaction and spontaneous or non-spontaneous reaction were found to be difficult for the students.

9.3 Conclusions

The proposed SCSMCC comprehensive model of conceptual change is based on my philosophy of education which set the theoretical landscape. Traditionally philosophies of education except Vygotsky's (1978) philosophy were dualist in nature. Where does knowledge reside in the mind of an individual or in the society? This is one aspect of dualist philosophy. In my research I adopted Vygotsky's monist philosophy of functional unity of individual mind and the society rather than monist philosophy of Spinoza which sees the universe made up of a single substance. Even though Vygotsky believed in the interdependence and functional unity of mind and society, he did not come up with his own ontology, epistemology, and methodology but used Marxian dialectical- historical materialism. My philosophy of

education, however, is based on my own definitions of ontology, epistemology, and methodology. Ontologically, I defined knowledge as a process that is spirally in transit between individuals and the society. There is no inside and outside duality or two important points which are not functionally unified, one point inside the mind and another point external to it, namely inside the society. The process has neither inside nor outside as it is not made up of points. Epistemologically, I defined the process of knowledge generation as a synergy of rationalism and empiricism. Empirical knowledge here is the knowledge generated as a result of experience due to social interaction. Methodologically, inquiry should be carefully balanced, integrated and meticulously planned spirally alternating between individual critical thinking involving reflections and group/social persuasion during collaboration. "Philosophy determines all elements of curriculum as well as aims, means, and ends of curriculum. It is the beginning point in curriculum decision making and is the basis for all subsequent decisions regarding curriculum. Above all, philosophy influences the content as well as organization of curriculum" (Ornstein and Hunkins, 2004:32-33)..

Vygotsky's theory is asymmetric in that it emphasizes the social more than the individual concomitant with his socialist philosophy. He took the social as primary and the individual as a derivative and secondary to the society. In my philosophy, however, in the initial point of learning a new concept or child development there is no difference between the social and the individual as individual use of the mind and support by the group/socio-cultural context are symmetrically evolving in a spiral manner along equiangular three dimensional conical helix at the base of which the individual and the social contributions of knowledge coalesce into a point. This is clearly explicated in the SCSMCC model which showed the cone of learning with the axis of symmetry. The axis of symmetry around which the spiral revolves and advances is what I called the axis of learning. The axis of learning is the direction along which deep learning occurs as a result of equal contribution of individual rational effort and group/socio-cultural contextual sharing of information. The distance between the axis of learning and the socio-cultural axis is called breadth or in Vygotsky's words the zone of proximal development. When the breadth is zero, the axis of learning coincides with the individual formation of concepts axis. The individual and social axes are equi-distant from the axis of learning. If either of the two axes disappears, the axis of learning coincides with the existing axis. And there is no plane of learning on to which the spiral cycle above it could be projected down and both breadth and depth of learning disappear. Our understanding should be based on history and culture and at the same time we should enable the individual to generate personal understandings using his mind. The change and growth of individuals and society are closely interconnected and evolve together without any need of primacy of one over the other.

The quantum mechanical law of conservation of parity states that the natural world is symmetrical and balanced. For example, matter and anti-matter are mirror reflections of each other's basic properties, left and right in most animals are mirror reflections of each other, negative and positive charges are symmetric in forming electrically neutral matter, etc. From this we can see that asymmetry or imbalance shows some sort deformity or lack of structure in the natural world. Asymmetry could be rejected on the grounds that it is simply unnatural and problematic in the natural world. Asymmetry is thus a perturbation or fluctuation from the natural symmetry. Symmetry shows "balance", "equilibrium", and "justice", in the case of human society. I believe in symmetrical relationships in research of social nature such as education. As such, owing to my background in physics, conservation of parity guided my thinking in educational research. I believed that a symmetrical theory of learning can be developed and it should be the right one. Based on this premise, I developed a symmetrical learning model for conceptual change by integrating individual and social constructions of knowledge. Rational innate ideas should be justified by experience or empirical evidence. And personal constructivism and social constructivism should form one unified and symmetrical system of knowledge generation. As such, individual cognition should be balanced by socio-cultural knowledge generation. Based on my symmetrical idea, I balanced the following in this research: rational ideas and experience; abstraction(symbolic representation) or theory building and concrete situation or context; instruction and assessment; procedural knowledge and conceptual knowledge; classroom and real world; theory and experiment(practice), etc.

"In the western world, the duality, society versus the individual, has been a major philosophical issue for centuries, and was very important in Dewey's works. This duality, allegiance to the society and fulfillment of the individual, is a noble aim that used to guide all curriculum specialists-from the means to the ends"(Ornstein and Hunkins, 2004:53-54). The western philosophers were clearly dualist and never believed in functional unity or monist philosophy of the eastern socialists or they are unable to see how this functional unity is achieved. Vygotsky(1978) himself came several times closer to using the idea of the spiral but not exactly to unify the individual and social contributions of knowledge construction as his asymmetric theory became a barrier to using it. The spiral by its very nature is symmetrical and that is why his asymmetric theory and his ideas of spiral were in a collision course. His asymmetric theory led him to conclude that "...history of development of each of the higher mental functions is not the direct continuation and further improvement of the corresponding elementary functions..." (Elkonin, 1999:42). But a symmetrical spiral model such as SCSMCC assumes development to progress continually. Vygotsky(1978) himself contradicted himself and argued, which I agree with, that development as frequently happens, moves not in a circle but along a spiral passing through the same point at each new revolution while advancing to a higher plane just above the point that was passed. Vygotsky (1978) used

the term spiral in the context of language learning (word-thought-word) and cognitive development. According to western philosophy, when many individuals grow and prosper, then the society flourishes because it is comprised of many individuals. The social constructivist's, however, believed that society is more than collection/sum of individuals. Education is growth and the meaning that the growth has for the individual and society. The question is, therefore, how to achieve a balanced and unified individual and societal development using education as a means. Such balanced and unified development must start at the classroom and household level.

In our educational system, are we stressing cognitive development only or the whole child? This research tried to give answer to this key question. My philosophy of education equally emphasizes both content and processes. A teacher should be a facilitator, elaborator, corrector, task/problem provider and checker of correct conceptions whether deeper understanding and conceptual change has occurred. Learner must be motivated and interested in the learning task. The classroom should be based on real-life experiences and well-organized content knowledge of text books. Students should be encouraged to express their views and share experiences and allowed to take position on controversial issues and concepts. They should not always conform to what the school presents as correct way of thinking or what the teacher says. At secondary level, school must use both cognitive learning and social interaction and combine personalized and individualized learning with collaborative and persuasive group experience sharing. The classroom should be characterized by cooperation, personal thinking and reflection, group activity and problem solving. The curriculum should be both individual-centered and society-centered and which tolerates unity and plurality of ideas. Students must not only take positions and advance their views but also become change agents to improve society. A dynamic curriculum such as this must address issues of both individual growth and societal development. Critical analytic pedagogies should be employed in schools which promote participatory, active-learning and learner-centered methods.

The curriculum should be using ideas from both "top-down" and "bottom-up" approaches. Ideas/contents forwarded according to international standards and local contexts by curriculum specialists and policy makers should not be approved without the engagement and consent of students, teachers, parents, community members and other stakeholders. Specialist standards should go hand in hand with needs assessment. In this way a harmonious, fruitful, relevant, humanist and disciplined curriculum can be developed. The curriculum should allow students to move from knowledge to activity, and from reflections to practical problem solving and involve students in deep critical understanding. In practice, most schools of thought combine various philosophies that is why I used an eclectic model of conceptual change which is based on individual growth and societal development. The idea is to improve the educational process, to enhance achievement of the learner, to produce better and more productive

citizens, and to improve the society as a whole. A prudent educational philosophy that serves the needs of individual students and society is always important and as a curriculum designer and developer we are continuously facing events of curriculum decision making and that is why philosophy is important in determining these decisions. I developed a model of conceptual change and it would be incomplete if I do not set its underlying philosophy which I described in the first paragraph of this conclusion.

When Vygotsky (1978) said that the 'social' is the source of personality development he was right but this one-sided approach neglects the contributions of individuals to societal development. He wrote of transition from the collective to the individual and this asymmetry is a key feature of his thoughts. However, he placed the dichotomy of the individual and the social within a unified whole and rejected the western Cartesian polarization of individual and society of Descartes. My symmetrical model assume development to progress continually in a spiral fashion allowing both individual growth and societal development to proceed as a unified whole. Vygotsky's (1978) asymmetry emphasizes the primacy of the social over the individual. I understand that the child requires guidance and nurturing but this should not lead us to assuming that s/he is incapable of learning using his/her mind. The safest educational theory is a symmetrical theory which bases all higher mental functions on lower mental functions and which equally values and balances the role of the individual and the social in learning.

According to Vygotsky (1978), in the beginning stages of child development both natural and socio-cultural components can be observed. Then how can we believe that development proceeds unidirectionally from external to internal mediation. In my SCSMCC as integrated model of conceptual change, development is bi-directional in which both natural and socio-cultural contextual factors synergistically work together and start from a single point of creation. Vygotsky(1978) considers development, as often happens, proceeds not in a circle but in a spiral, passing through the same point at each new revolution while advancing to a higher level. But I contend that if development is such a continuous process, how can at the same time Vygotsky considers a discontinuity between the lower, elementary functions and the development of higher mental functions. This apparent paradox involving discontinuity in cognitive development is resolved by the SCSMCC which is a symmetrical and continuous model. If I personally agree that internal reconstruction of an external operation as internalization, then I should symmetrically call external organization/reconstruction of an internal operation externalization or verbal thought/speech. School learning introduces systematic learning which Vygotsky called Zone of Proximal Development (ZPD). He defined ZPD as a distance between the Actual Development Level (ADL) as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers. According to ZPD, the only "good learning" is that which is in advance of

development (Vygotsky, 1978). Learning creates the ZPD, when internalized it becomes ADL. In infancy, Vygotsky claims, the interactions with adults are asymmetrical. However, in SCSMCC new concepts are considered like a new born child and the process of internalization must be complemented with the process of externalization. SCSMCC claims itself to be a symmetrical model of child and adult interaction or individual/personal thinking and social interaction. There should be a symmetrical interaction between the natural and the socio-cultural contexts. Asymmetry simply creates dependence of the child on adults or social group and erodes the balanced self-confidence of the child or individual.

Constructivism is set out in 1970s to overcome the Cartesian mind-body dualism and the debates between empiricism and rationalism. Constructivism was praised for its emphasis on learners' active participation and heightened recognition to the social nature of learning (Philips, 1995). Constructivism's initial monist stance soon fell back to dualist position again because of sectarian views created in it. By arguing for individual or social construction of knowledge the Cartesian parallelism or dualism between individual and social has again arisen. The SCSMCC tries to restore the initial monist stance of constructivism. Behaviorism and cognitivism took knowledge as mechanically and rationally acquired respectively. Constructivism incorporates human subjectivity excluded by behaviorism and cognitivism. The Cartesian dualism which was rejected in 1970s crept in again via radical and social constructivism. It was no more one philosophy as it is in the outset.

Radical constructivism considers social environment and interaction to serve as stimulus only for individual thinking or construction of knowledge. Social constructivism considers learners to be encultured into their learning community and appropriate knowledge based on their existing understanding and through interaction with their immediate learning environment. Learning is thus largely considered situation-specific and context-bound activity. Personal constructivism argues that nature has no mind-independent existence and all individuals should not be expected to have uniform cognition. Social constructivism, on the other hand, argues that each situation or context is unique and cross-community transfer of learning, if not impossible, is difficult. Both of the above arguments lead to epistemological relativism in which any truth is as good as any other.

The SCSMCC, however, shows an equal contribution of the mind and social environment in learning is depicted along the axis of learning in my cone of learning in Figure 1.1. I agree with Vygotsky about the functional unity of mind and social environment in learning and thus restore the monist philosophy of constructivism set out in the 1970s but I do not agree with his asymmetry of social primacy over the individual. Piaget equally valued the individual and the social, even though he was a personal constructivist, and still emphasized the personal construction of knowledge over the social. He said that

the collective intellect is the social equilibration resulting from the interplay of the operations that enter into all cooperation. Kuhn (1962) rejected that the intellectual is the result of the social. Lave and Wenger (1991) using their situated learning theory disapproved Vygotsky's (1978) concepts of internalization, generalization, and scientific concepts for they contain only "a small 'aura' of socialness". Vygotsky considers the role of social collectivity in individual learning and development but ignores the role of the individual. Dualists polarize the individual and the social and take them as fundamentally separate from each other. The SCSMCC values both the individual and the social as equally important in learning and there is no need to assert that one is primary and the other is secondary.

The symmetric and hence balanced model is more appropriate than the asymmetric models of Vygotsky (1978) and Piaget (1978). They also admit that mind is not totally independent of the social and cultural group but emphasize one over the other. Individual and social development should be spiral in nature as mind and social environment are not mutually exclusive. If Vygotsky (1978) himself argued that mind and socio-cultural environment are functionally unified and not mutually exclusive, how can we ascribe asymmetry or emphasize one over the other at any stage of development? Vygotsky followed a linear reasoning of concrete to abstract and such linear reasoning cannot support the wholeness/unity of the psychological and the socio-cultural environment of child development and learning. Education, therefore, should at the same time involve both enculturation and development of individual intellectual skills which transcends specific socio-cultural context.

Situated learning theory of Lave and Wenger (1991), is also another asymmetry like that of Vygotsky (1978) which suggests "learning is bound to specific concrete situation in which it occurs, and transfer is difficult, if not impossible" (Eggen and Kauchak, 1999:285). Learning that happens in one specific situation/context is unstable to be transferred to another similar situations which are still different. A theory that does not address properly the problem of learning transfer is clearly an inadequate learning theory (Vosniadou, 2007). The asymmetry in situative theory of learning considers individuals as non-initiative beings which receive one-sided external forces from the social (Lave, 1988). Philosophically, the social/collective is not a mere total sum of separate individuals and we cannot sum individuals because they are not equal. The collective is always larger than the total sum of individuals and it has a qualitatively different existence (Vygotsky, 1978). Vygotsky tried to connect the individual consciousness and the collective through the collective subjectivity and this collective subjectivity is not clearly conceptualized or objectively asserted. Therefore, in SCSMCC as integrated model of conceptual change, the conception of the social and individual being closely interconnected, functionally unified, constantly interacting, and the change and development in one relentlessly influencing the other provide a valid explanation for both individual and social development.

Contextual learning is as important as intellectual skills which transcend them. In the integrated model of conceptual change, critical thinking and reflection provides the essential knowledge and skills which connect different contexts. Students are required to question context-specific beliefs and assumptions and dig deeper into concepts which provide relationships between different situations. In the SCSMCC even though not significant, there are changes in thermodynamics achievement of 3.18 on a scale of 27 from Physical Thermodynamics to Chemical Thermodynamics which showed some knowledge transfer. And concomitantly there is a significant attitudinal change when learning occurs in closely similar contexts as shown in Chapter eight of this thesis. Therefore, both cognitive and motivational positive transfers/changes have been observed using SCSMCC as holistic model of conceptual change in two similar contexts. And also a significant negative attitudinal transfer has been observed from physics to chemistry. The SCSMCC as comprehensive model of conceptual change has the power to address the issue of knowledge transfer better than situative learning theory, social constructivism, and personal constructivism. Social constructivism fails to show how the external world can be bridged to the internal world. And personal constructivism also fails to address how the internal world can be bridged to the external world. The asymmetry also lies in Vygotsky's emphasis on internalization by individuals and should have been complemented with externalization or communicative speech by same individuals so that learning fosters both individual and socio-cultural development. If the individual will not reciprocate internalization with externalization, it is not going to be a healthy psychosocial learning. Language used in externalization is only one form of experience and excludes others such as perceptual experience, tacit knowledge or knowledge that is not clearly articulated. We do know more than knowledge that we externalize via language and sometimes our knowledge is simply a tip of the iceberg. Therefore, to argue that all knowledge is based on language but not as a carrier of explicit/externalized knowledge is simply over generalization and extreme asymmetry. What about knowledge of infants in their pre-linguistic phase and knowledge of animals such as primates?(Fox, 2001).

It remains uncertain that how much of knowledge gained through social interaction is internalized and how much of knowledge we have in our mind is externalized through the use of language. Language mastery facilitates and develops our ability to think, organize our higher mental thinking and surface what we have in our minds. Therefore, language will help us both in facilitating internalization, develop and restructure our schema, and also help us in externalization using alternative, precise and robust representations. Language helps us develop our conceptual system and even think more and generate better language or intellectualize us. The change and growth of the society and individuals are closely interconnected and we cannot say that one precedes the other, if we can say that we can finally end up at

chicken and egg dilemma and it is safer to assume that they started at about the same time. Teaching and learning starts at about the same time. If the socio-cultural environment is the birth place of language and thinking, why is there a difference in individual's language use and mental activities when they grew up in the same socio-cultural environment?(Hualiu and Matthews,2005). Individuals are different based on the way they generate knowledge.

Spinoza's monism considers the universe as consisting of singular substance but Vygotsky's functional monism views that all living factors exist in interdependency and form a dialectic organic whole. In SCSMCC, the cone of learning and its axis of learning show that the search for truth will be an eternal cause and we cannot objectively assert causally that the society causes the individual. Therefore, it is better to use a balanced, symmetric and monist philosophy as well as the theory of learning that equally values individual and societal development. The SCSMCC resolves the apparent paradox created by Vygotsky's(1978) and Piaget's (1978) asymmetric theories. The SCSMCC also states that if the society, as the birth place for individual development can constrain and distort human personality, how can it also expand and free it. The position of asymmetry is not only from Vygotsky's side but also from personal constructivists' side, since for them, individual construction of knowledge is primary and the social construction of knowledge is secondary and derivative (von Glasersfeld, 1995). The new model cannot accept asymmetry of any nature because it may result in the paradox stated earlier from each angle. From the social side it deprives the learner self-monitoring and self-discovery in relation to others and from the individual side it deprives the learner the power to adjust himself to social reality.

The model also has shown good rate of knowledge transfer, in addition to deep conceptual understanding, which is better than other theories such as social constructivism, situated learning theory or radical constructivism as stated above. Deep conceptual understanding with associated procedures is another result of the new conceptual change approach. The model also enhanced the performance of low achievers and girls. The SCSMCC as integrated and symmetrical (balanced) model of conceptual change has been applied throughout this thesis to ensure internal consistency. Balance of individual and societal development, conceptual knowledge and procedural knowledge, the context and the abstract, etc. are some of the examples.

9.4 Implications of the SCSMCC as Symmetrical-Integral Model of Conceptual Change for Curriculum Design and Development

One lesson learned from the experiment is that teachers should be trained to teach beyond facts and procedures. The curriculum should practically and actively engage students in abstract thinking, deeper understanding and sophisticated performance. We should foster a curriculum which balances factual,

conceptual and procedural knowledge. Such type of curriculum should consider thinking beyond the facts and beyond calculating one right numerical answer, but facilitate deep understanding, conceptual change and the transfer of knowledge. The curriculum should systematically develop a conceptual schema in the brain of learners to handle new information. The SCSMCC as integrated model of conceptual change has the power of meeting higher academic standards regarding content knowledge, process abilities, and quality performance. Curriculum units which are coherent and focused should use instruction that engage students with higher level thinking and deep understanding. Traditional curriculum values memorization more than the development of abstract thinking ability. In constructivist curriculum, conceptual knowledge should be related to critical content and process abilities in a given discipline.

The constructivist curriculum should be coherent in that it holds together parts and make sense as a whole. Its parts, whatever they are, should be unified and connected by the sense of the whole. Attributes of coherent curriculum are purpose, unity, relevance and pertinence. In every discipline, there are significant basic concepts to organize learning experiences around them. Students should learn to go beyond information reception by applying constructivist conceptual change curriculum, critical analytic pedagogies through reasoning, justification, critical analysis, persuasion, collaboration and application. Students should be allowed to explain in their own words; they should exemplify; they should apply; they should justify; they should compare and contrast; they should contextualize; they should learn to apply and develop abstractions; and they should generalize. Curriculum documents should not frame goals such as "students will understand that heat is a form of energy transfer" unless the teachers have themselves a clear basic conceptual ideas of the discipline and a conceptual change model such as SCSMCC as holistic model of conceptual change help them teach facts, procedures, and concepts in a balanced manner.

Our science curricula should be idea (concept)-centered rather than topic-centered. According to Mc Neil (1996), topic-centered curriculum focuses heavily on memorization of facts and *assumes the development of deeper ideas*. Idea (concept)-centered curriculum *focuses on deeper, conceptual ideas and use facts and procedures to support complete understandings. Facts are means not ends for this type of curriculum* (emphasis added) (Amare, 2009:429).

What is then a concept? A concept is an organizing idea; a mental construct... which is: timeless, universal, abstract, broad, represented by one or two words, and examples of which share common attributes (Erickson, 1998). Examples may differ in context, but they have common attributes. Symmetry can have different examples, but all examples display the attributes of "balance". We need to balance procedural knowledge and conceptual knowledge, as the new secondary school curriculum did not

balance them. The new secondary science curriculum is not purely constructivist as there are methods which are teacher-centered in the curriculum guides. The curriculum is not showing clearly whether it is using a dualist or monist philosophy of education. Whether the authors used radical constructivism or social constructivism or some combination of them is not clear from the curriculum documents. Explicit conceptual change strategies were not used in the new secondary science curriculum. The existing curriculum should change because it lacks conceptual change strategies and full-fledged constructivist strategies. It mainly uses combined methods of teaching which employs both learner-centered and teacher-centered methods. There are lots of conceptual and technical errors in the curriculum which merit its revision or change. For example, author induced misconceptions in the writings of the first law of thermodynamics and drawing errors such as those shown in heat engine which violate the second law of thermodynamics.

The new secondary physics curriculum did not balance factual, procedural and conceptual knowledge and they are not properly sequenced. Secondary school teachers lack skills in constructivist methodologies and proper training should be given to secondary school teachers regarding the implementation of constructivist strategies. Resources are not available for some constructivist strategies recommended by the authors of the new so called constructivist curriculum. Assessment methods recommended by the authors of text books are not supporting conceptual understanding and they are checking for speed and accuracy in procedural understanding. Conceptual understanding can help generate alternative procedures and even find new facts for solving problems. Therefore, the assessment was not compatible with the so called constructivist curriculum. All of the above and other factors require the existing curriculum to be either revised or changed. Any new curriculum should balance individual and social formation of concepts as shown in the SCSMCC as integrated model of conceptual change. In the structure of knowledge we need to teach: basic concepts, principles as relationships between concepts, laws as abstractions of relationships between concepts, and theory as comprising relationships between groups of laws in an internally consistent manner.

Based on Erickson(1998) idea, in order to develop increasing sophistication in conceptual understanding and associated procedures, two things need to occur in curriculum design:

- (1) Concepts need to "spiral" through grade levels. The concept remains the same, but the topics change. Students develop increasing conceptual understanding with associated procedures related to a given concept at different grade levels but meet new and robust examples.

- (2) Generalizations (essential understandings) are identified in the planning process. The goal is to teach students to think conceptually and procedurally in a balanced manner. This only happens if teachers identify and teach the basic concepts which underlie the procedures of a discipline.

Disciplinary, multidisciplinary, and interdisciplinary units can be designed using concept-centered curriculum. According to Erickson (1998), there are two major reasons why curriculum design should shift from a topical focus to a conceptual focus:

- (1) *Knowledge is expanding exponentially. We cannot just add a new science text each year. Students need to learn the skills of accessing multiple data sources and applying the skills of critical, creative and integrated thinking to assimilate, sort, and pattern information.*
- (2) *In this world of rapid change and global interaction, citizens need conceptual thinking abilities to understand increasingly complex relationships.*

“What is the difference between a “theme” and a “concept”? A theme can be topical such as “Thermodynamics” or “Thermochemistry”. Concepts are a one or two word mental constructs, that is, they can be broad, abstract, timeless, universal, and represents a variety of examples that all share the attribute of the concept”(Erickson, 1998). We should also create a bridge between performance-based activities and deeper, conceptual understandings. In concept-based curriculum, misconceptions need to be addressed. Concept-process integration and balance will reinforce and lead to deeper understanding of discipline-based concepts when students experience their application in broader contexts. This means that insisting on conceptual depth and understanding and while at the same time focusing on the development of procedural skills is important in the constructivist conceptual change curriculum.

9.5 Recommendations for Further Research

In any future curriculum, all factual, procedural, and conceptual knowledge should be balanced. Justifications should be provided for using teacher-centered methods in a claimed mainly constructivist curriculum such as the one we have now in our secondary science curriculum. In any future study, the problem of knowledge transfer should be investigated carefully. Replication studies should be conducted by any other person in the field of science education in order to recheck the validity of my SCSMCC as integrated model of conceptual change and the accompanying RPC method. Authors of science curricular materials should consider both horizontal and vertical coordination of subjects' concepts. In addition to selection of highest standards in the development of our curriculum by specialists, we need careful needs assessment and investigation of resources available in schools before trying to attempt and develop a new curriculum.

To overcome students' misconceptions a carefully planned lesson on correct and incorrect conceptions of science should be made in the interest of not wasting class time. Author(s) induced misconceptions last longer as the students tend to take for granted or as a finished product the contents of science. Therefore, author(s) should look for sources of misconceptions while writing curricular materials along with learning strategies which are effective to overcome them. In any future study, students of science should be made aware of teaching/learning strategies which are going to be used before classes commence in order for them to be cooperative during the instructional transaction(s). Teaching method(s)/learning strategies which combine both individual learner efforts and group/social mediation of knowledge should be checked and rechecked in any future study.

In an introduction and throughout any lesson, the gate keepers such as motivation, affection and socio-cultural contextual factors should be activated. The effect of classroom contextual factors on conceptual understandings should be investigated. Research on students' misconception or alternative conceptions of science content should be encouraged and results obtained should be used by authors of curricular materials and school teachers. Research on effective teaching methods and models should continue in content specific areas. Sufficient on-the-job trainings should be provided to school teachers when ever new pedagogical techniques and learning theories appear plausible. Meta analysis of science teaching methods should be made and based on it we should select those methods which fit local contexts. Author(s) of science curricular materials should be very careful not to make errors in: paragraphing, grammar, drawing, illustrations, equations, symbols, organization, of knowledge which makes flow of knowledge very clear, etc.

Author(s) of science curriculum materials should engage elements of science abstraction such as symbolic representation and theory building and also value empirical evidence in addition to their rational thinking. Acquisition of knowledge should be viewed as interplay of individual cognitive component and socio-cultural factors. The SCSMCC as integrated model of conceptual change and the accompanying RPC method should be tested in other domains of science. Further research should be conducted to refine the SCSMCC as holistic model of conceptual change and best methods which accompany it. The value of SCSMCC as integrated model of conceptual change in lifelong learning should be investigated as it is not limited only to classroom learning. The spiral model of conceptual development should be tested in curriculum design and development at all levels of science and at all domains of learning. The blend of context dependence and context independence of SCSMCC should be investigated in any future study. The sequence and balance of factual, procedural, and conceptual knowledge should be a subject of any future study. We should investigate whether the breadth is equal to the zone of proximal development

(ZPD) in any higher plane of learning in my cone of learning in which the spiral advances and evolves. Further research should be conducted on as to why the apparent paradox that background knowledge-well established in psychological literature as a facilitator of learning-often served as a barrier to knowledge change. Further research should identify individual goals, purposes, and intentional hot constructs that can resolve this apparent paradox. Also why students with similar background knowledge may have differing degree of conceptual change and knowledge restructuring and why motivational constructs may facilitate or hinder conceptual change or why they serve as a double-edged sword. And whether they have a mediating/indirect role or direct role in the process of conceptual change or how they might be embedded in specific classroom contexts. Further research should be conducted on why students with differing achievement goals and epistemological beliefs might have different rates of knowledge restructuring and conceptual change. And also how learner's own context might affect the likelihood of conceptual change and knowledge restructuring or why intentional learners would change their conceptions with minimum resistance. Further research should be conducted as to why domain general motivational constructs when applied to specific domain and classroom context might result in different learning outcomes. More research is needed for classroom contextual factors in conceptual change in which we should examine how patterns of classroom interactions and instructional contexts promote or restrict conceptual change. And, therefore, further research should be conducted to test and retest the validity of symmetric learning theory in contrast to the established asymmetric learning theories.

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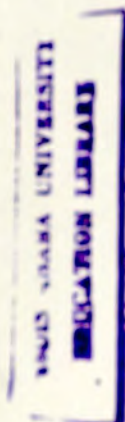
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APPENDICES

APPENDIX A: G-12 Physics, Conceptual and Procedural Test on Unit 1, 'Physical Thermodynamics'

Contents to be covered	Weightage count of 30 questions
- Heat transfer	3
- Kinetic theory of an ideal gas	2
- The laws of thermodynamics(0 th , 1 st , 2 nd)	10
- Isothermal and adiabatic processes	3
- Equation of state	3
- Temperature and pressure	3
- Heat engines and refrigerators	3
- Heat, work and internal energy	3

To the Respondent

The following questions will help you understand the forthcoming topics in your study or test your understanding of what you have learnt so far. Choose the best answer that represents your conceptual understanding of the situation for the first 27 questions and there are three procedural questions which can be solved in the space provided. There are a total of 30 questions to which you can respond. I thank you in advance for participating in answering these questions.

Part I: Conceptual Questions (27 Questions)

- As a state of a substance change from solid to liquid, and from liquid to gas; the mean free path(average distance between molecular collisions)
 - increases
 - decreases
 - stays the same
- What happens to the entropy (disorder) of a cube of ice as it is melted?
 - It increases
 - It decreases
 - It stays the same
- What happens to the entropy of a piece of wood as it is burned?
 - It increases
 - It decreases
 - It stays the same
- The thermodynamic processes that occur in nature _____.
 - Convert thermal energy in to mechanical energy
 - Lead to a more ordered state
 - Cannot be reversed
 - Cannot be conserved
- According to the second law of thermodynamics, it is impossible for _____.
 - Heat energy to flow from a colder body to a hotter body

- b. An ideal heat engine to have the efficiency of 99%
 - c. An ideal heat engine to have power greater than 0.1w
 - d. A physical process to yield more energy than what is put in
6. Why must every heat engine have a cold reservoir?
- a. Because it is impossible for even a perfect engine to convert heat entirely into mechanical work
 - b. Because the cold reservoir keeps the engine from overheating.
 - c. Because the cold reservoir keeps the engine from overcooling.
 - d. Because the cold reservoir increases the power of the engine.
7. In a real isothermal expansion, the temperature of the surroundings must be _____ the temperature of the gas.
- a. Greater than b. Less than c. Equal to
8. The thermal efficiency of a Carnot engine increases when:
- a. ratio of T_{cool} reservoir and T_{hot} reservoir is small. b. T_{hot} reservoir is large. c. T_{cool} Reservoir is small d. there is no cold reservoir
9. In a real isothermal compression, the temperature of the surroundings must be _____ the temperature of the gas.
- a. Greater than b. Less than c. Equal to
10. Which of the following conditions should be met to make a process perfectly reversible?
- a. Any mechanical interactions taking place in the process should be frictionless.
 - b. Any thermal interactions taking place in the process should occur across infinitesimal temperature of pressure gradients
 - c. The system should not be close to equilibrium
11. $\Delta U = Q - P\Delta V$
This form of the first law of thermodynamics is valid when:
- a. Heat is given off by the system and work is done by the system
 - b. Heat is absorbed by the system and work is done by the system
 - c. Heat is absorbed by the system and work is done on the system
 - d. Heat is given off by the system and work is done on the system
12. The boiling temperature of a liquid _____ with pressure
- a. decreases
 - b. increases

- c. stays the same
- d. Not enough information is given to determine
13. An ideal gas undergoes an isothermal process, where the specific volume increases. Does the entropy of the gas:
- Increase?
 - Decreases?
 - Stay the same?
 - Not enough information is given to determine.
14. For isothermal process:
- $\Delta U=0$
 - $\Delta U=\Delta Q$
 - $\Delta Q=0$
 - $\Delta U=\Delta W$
15. A pressure of a gas is due to:
- Rapid intermolecular collisions
 - Molecular impacts against the walls of the vessel
 - Voids between the gas molecules
 - Ideal behavior of gases
16. A closed flask contains H_2O in all its three states: solid, liquid, and vapor at $100^\circ C$. In this situation the average kinetic energy of the molecules
- Highest in vapor state
 - Same in all the three states
 - Greatest in solid state
 - Greater in liquid than in vapour state.
17. Which of the following is a correct plot of the volume of fixed amount of ideal gas a function of temperature (at constant pressure)?
- -
 -
 -
18. Ice at $0^\circ C$ is melted by adding hot blocks of metal. One option is to use one metal block at a temperature of $200^\circ C$ to melt ice and a second option is to use two metal blocks each at a temperature of $100^\circ C$ to melt ice. The metal blocks are identical in every way except for their temperature; however, since there are two blocks at the lower temperature, they have twice the mass, which option will melt the ice at a faster rate?

- a. One metal block at 200°C
- b. Two metal blocks each at 100°C
- c. Both

19. What happens to the temperature of something that radiates energy without absorbing the same amount in return?

- a. It drops
- b. It rises
- c. It remains the same

20. The transfer and distribution of heat energy that moves from molecule to molecule with in a substance is :

- a. Conduction
- b. Convection
- c. Radiation
- d. None of the above

21. The transfer of heat energy in a gas or liquid by means of currents in the heated fluid is :

- a. Conduction
- b. Convection
- c. Radiation
- d. None of the above

22. The transfer of energy at the speed of light by means of electromagnetic waves is:

- a. Conduction
- b. Convection
- c. Radiation
- d. None of the above

23. The pressure exerted against the ground by an elephant's weight distributed evenly over its four feet is less than one atmosphere. Why, then, would you be crushed beneath the foot of an elephant while you are unharmed by the pressure of the atmosphere? Explain

24. In a refrigerator

- a. heat can flow from a colder to a warmer body
- b. heat cannot by itself flow from a colder to a warmer body
- c. to transfer heat from low temperature to higher temperature external work is not required
- d. external work is not required for it to function

25. A process, usually of expansion or compression, where in not heat enters or leaves a system is:

- a. Isothermal
- b. Adiabatic
- c. Isochoric
- d. Isobaric

26. In a Carnot cycle, we have

- a. two adiabatic and one isothermal paths
- b. one adiabatic and two isothermal paths
- c. two adiabatic and two isothermal paths
- d. one adiabatic and one isothermal paths

27. Internal energy of an idea gas is proportional to

- a. the pressure of the gas
- b. the temperature of the gas
- c. the volume of the gas
- d. the heat of the gas

Part II: Procedural Questions(3 Questions)

1) a) Water at the top of Tiss Abay Falls has a temperature of 20°C . It falls through a distance of 40m. Assuming that all of its potential energy goes into warming of the water, calculate the temperature of the water at the bottom of the Falls?

- b) Calculate the height that a block of ice at 0°C must be dropped to completely melt upon impact? Assume no air resistance and that all the energy goes into the melting ice. Take heat of fusion as $334,000$ joules per kilogram. Do you see why the answer doesn't depend on mass?
- 2) How much work is done by the steam when 1 mol of water at 100°C boils and becomes 1 mol of steam at 100°C and at 1 atm pressure? Assuming the steam to be an ideal gas, determine the change in internal energy of the steam as it vaporizes?
- 3) An ice tray contains 500 g of water at 0°C . Calculate the change in entropy of the water as it freezes slowly and completely at 0°C ?

APPENDIX B: G-12 Chemistry, Conceptual and Procedural Test on Unit 3, 'Chemical Thermodynamics'

Contents to be covered	Weightage (out of 30 questions)
- Spontaneous processes	1
- Internal energy	3
- Heat	3
- Work	3
- 1 st and 2 nd law of thermodynamics	10
- Understand concepts of enthalpy, entropy and entropy changes, free energy changes, chemical equilibrium, and Hess's law.	10

To the Respondent

The following questions will help you understand the forthcoming topics in your study or test your understanding of what you have learnt so far. Choose the best answer that represents your conceptual understanding of the situation for the first 27 questions and there are three procedural questions which can be solved in the space provided. There are a total of 30 questions to which you can respond.

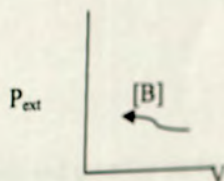
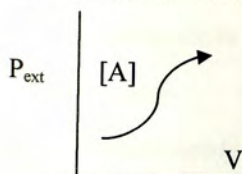
I thank you in advance for participating in answering these questions.

Part I: Conceptual Questions(27 Questions)

1. A gas is contained in a sealed, frictionless, piston-cylinder arrangement, where the piston mass and the atmospheric pressure remain constant. The gas is heated and expands in the cylinder. In this process:

- Work is done on the gas
- Work is done by the gas
- No work is done
- Insufficient information

2.



- [A] work done on system, [B] work done by system

- b. [A] work done by system, [B] work done on system
 - c. [A] work done on system, [B] work done on system
 - d. [A] work done by system, [B] work done by system
- 2) [A] work done by system ($dv > 0$, $w > 0$) increasing volume, expanding work done by the system
 [B] work done on system ($dv < 0$, $w < 0$) decreasing volume, contracting work done on system
3. When a thermodynamic system has under gone a cyclic process.
- a. The net change in internal energy of the system is always zero.
 - b. The net work done must be zero.
 - c. The system and the surroundings must have returned to their.
 - d. Initial state.
 - e. None of the above.
 - f. All of the above
4. $\Delta U = Q - P\Delta V - V\Delta P$
- This form of the first law of thermodynamics is valid for
- a. All processes
 - b. Processes where changes in KE and PE are zero.
 - c. Quasi-static processes where changes in KE and PE are zero
 - d. Quasi-static processes of an ideal gas where changes in KE and PE are zero
 - e. All quasi-static processes of an ideal gas
 - f. All quasi-static processes.
 - g. None of the above.
5. In an adiabatic ($Q=0$) steady flow compressor, the magnitude of the shaft work done by the system (neglecting kinetic and potential energy), is equal to:
- a. The change in enthalpy
 - b. The change in internal energy
 - c. None of the above
 - d. I don't know
6. In a quasi-static steady flow process (neglecting kinetic and potential energy), the magnitude of the total work done by the system is equal to:

- The change in enthalpy
 - The change in internal energy
 - None of the above
 - I don't know
7. Frequently we model turbines as being adiabatic and quasi-static and neglect changes in kinetic and potential energy. For such a device operating with air as an ideal gas ($R=287 \text{ J/kg}^\circ\text{K}$; $C_v=716.6 \text{ J/kg}^\circ\text{K}$; $C_p=1003.5 \text{ J/kg}^\circ\text{K}$) which of the following is true?
- $W > W_{\text{shaft}} > 0 > F_{\text{flow}}$
 - $W_{\text{shaft}} > W > 0 > W_{\text{flow}}$
 - $W_{\text{shaft}} > W > W_{\text{flow}} > 0$
 - $W > W_{\text{shaft}} > W_{\text{flow}} > 0$
 - I don't know
8. Which of the following reverse state transitions (from 2 to 1) are consistent with the first law of thermodynamics?

A: State 1: Two identical blocks of copper are put in contact. One is at 200K, the other is at 300K. The two (together) are thermally-insulated from the environment. State 2: Blocks of copper now at $T=250\text{K}$.

B: State 1: A flywheel is spinning in air in a thermally-insulated rigid container. The flywheel and air are at the same temperature. State 2: the flywheel has stopped and the air temperature is higher.

C: State 1: Gas x fills half of a rigid container and another gas Y occupies the other half. The temperature is T. State 2: The gases are uniformly mixed throughout the container and the temperature is T.

- 1) A 2) B 3) C 4) All of them 5) None of them 6) I am not sure

9. Which of the following reverse state transitions (from 2 -1) do you think can occur spontaneously?

A: State 1: Two identical blocks of copper are in contact. One is at 200K, the other is at 300K. the two (together) are thermally insulated from the environment. State 2: Blocks of copper now at $T = 250^\circ$

B: State 1: A flywheel is spinning in air in a thermally-insulated rigid container. The flywheel and air are at the same temperature.

State 2: the flywheel has stopped and the air temperature is higher.

C: State 1 Gas K fills half of the rigid container and another gas Y. occupies the other half. The temperature is T. State 2: the gases are uniformly mixed throughout the container and the temperature is T.

- 1) A 2) B 3) C 4) All of them 5) none of them 6) I am not sure

10. List any consequences of the 2nd law of thermodynamics

- _____
- _____
- _____
- _____

11. An ideal gas undergoes an isobaric process where the temperature increases. Does the entropy of the gas:

- Increase?

- 2) Decrease?
 - 3) Stay the same?
 - 4) Not enough information is given to determine
12. An ideal gas undergoes an isochoric process where the pressure increase. Does the entropy of the gas:
- 1) Increase
 - 2) Decrease
 - 3) Stay the same?
 - 4) Not enough information is given to determine
13. In a combustion reaction, the energy released as the products form is
- 1) Less than the energy required to break apart the reactants.
 - 2) More than the energy required to break a part the reactants.
 - 3) Equal to the energy required to break apart the reactants.
 - 4) Impossible to determine
14. The enthalpy change for a reaction is determined by
- 1) Subtracting the reactants
 - 2) Subtracting the Enthalpy of the reactants from the enthalpy of the products
 - 3) Adding the enthalpy of the products to the enthalpy of the reactants.
 - 4) Driving the enthalpy of the products by the enthalpy of the reactants.

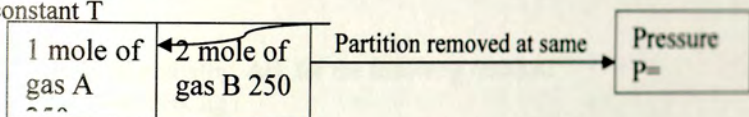
For questions 15 and 16 considered a situation in which twenty 100g aluminum plates and twenty 100g wooden plates have been stored overnight in a freezer. These plates were designed to be the same size and shape.

15. How do the temperatures of the aluminum and wooden plates compare when first removed from the freezer?
- 1) The aluminum plates will be at a lower temperature.
 - 2) The wooden plates will be at a lower temperature.
 - 3) Both will be at the same temperature.
 - 4) Usually the aluminum plates will be at a lower temperature.
 - 5) Usually the wooden plates will be at a lower temperature
16. One minute after they have been removed from the freezer and placed on a table in the same environment how will the temperatures of the wooden and aluminum plates compare?
- 1) The aluminum plates will be at a lower temperature
 - 2) The wooden plates will always be at a lower temperature
 - 3) All the wooden and aluminum plates would be at the same temperature.
 - 4) Usually the aluminum plates will be at a lower temperature
 - 5) Usually the wooden plates will be at a lower temperature
17. Which of the following statements describes the difference between a strong chemical bond and a weak chemical bond between two atoms?
- i) The strong chemical bond stores more energy than the weak chemical bond
 - ii) More energy is needed to separate strongly bonded atoms than weakly bonded atoms
 - iii) More energy is released to the environment when two atoms become strongly bonded than when two atoms become weakly bonded.
- 1) i only
 - 2) ii only
 - 3) iii only
 - 4) ii and iii only
 - 5) i, ii, and iii

18. The air conditioning breaks down room. In an attempt to keep the room cool for the rest of the afternoon you open the door of a refrigerator that you have in your room. Over the rest of the afternoon what effect will the open refrigerator have on the temperature of your room
- 1) It will decrease it significantly
 - 2) It will decrease it only slightly
 - 3) It will have no effect

- 4) It will increase it
- 5) It depends on whether the refrigerator is set to keep food cold or very cold.
19. What happens to the weight of iron nails when they rust?
- 1) There is no change in the weight.
 - 2) The weight increases
 - 3) The weight decreases
20. Kinetic energy is proportional to the temperature of a gas and is given by $K_{ave} = \frac{3}{2} KT$. For ideal monatomic gas of N particles is given by $U = N (K_{ave}) = \frac{3}{2} NKT$. Therefore
- 1) The temperature, average kinetic energy and total internal energy of the gas are directly proportional to each other.
 - 2) The temperature, average kinetic energy, and total internal energy are inversely proportional to each other
 - 3) They are related in an unknown way.
 - 4) The information is not sufficient.
21. Which of the following plot will be linear with slope equal to zero in case of ideal gas?
- 1) V vs. T at constant P
 - 2) V/T vs. T at constant P
 - 3) $\log P$ vs. $\log V$ at constant T
 - 4) P vs. T at constant T

22.



In this experiment, the value of P is

- 1) 250mm
 - 2) 500mm
 - 3) 300mm
 - 4) 400mm
23. At constant volume for a fixed number of moles of a gas, the pressure of the gas increases with the rise in temperature due to:
1. Increase in average molecular speed.
 2. Increase in rate of collisions.
 3. Increase in molecular attraction.
 4. Increase in mean free path.
24. Heat is added to a sample of water in an insulated container. Which one of the following statements is necessarily true?
1. The temperature of the water will rise.
 2. The volume of the water must decrease.
 3. The mass of the system must decrease.
 4. Under certain conditions, the temperature of the water can decrease.
 5. The type of change that will occur depends on the original temperature of the water.
25. Which one of the following substances have the highest entropy (s)?

indicates its number in SAI II. The numbers 1 to 5 represent a five point Likert scale where 1= "strongly disagree", 2= "disagree", 3= "neutral", 4= "agree" and 5= "strongly agree". Answer the questions by circling the number that best expresses your feeling.

1-A	The laws and/or theories of science are approximations of truth and are subject to change.	1 2 3 4 5
4	Scientists are always interested in better explanations of things.	1 2 3 4 5
16	Scientific ideas can be changed.	1 2 3 4 5
34	Scientists believe that nothing is known to be true for sure.	1 2 3 4 5
1-B	The laws and/or theories of science represent unchangeable truths discovered through science.	1 2 3 4 5
11	When scientists have a good explanation, they do not try to make it better.	1 2 3 4 5
15	Scientists discover laws which tell us exactly what is going on in nature.	1 2 3 4 5
35	Scientific laws have been proven beyond all possible doubt.	1 2 3 4 5
2-A	Observation of natural phenomena and experimentation is the basis of scientific explanation. Science is limited in that it can only answer questions about natural phenomena and sometimes it is not able to do that.	1 2 3 4 5
10	Scientists cannot always find the answers to their questions.	1 2 3 4 5
19	Some questions cannot be answered by science.	1 2 3 4 5
33	The senses are one of the most important tools a scientist has.	1 2 3 4 5
2-B	The basis of scientific explanation is in authority. Science deals with all problems and it can provide correct answers to all questions.	1 2 3 4 5
2	Anything we need to know can be found out through science.	1 2 3 4 5
7	We can always get answers to our questions by asking a scientist.	1 2 3 4 5
26	If a scientist cannot answer a question, another scientist can.	1 2 3 4 5
3-A	To operate in a scientific manner, one must display such traits as intellectual honesty, dependence upon objective observation of natural events, and willingness to change after one's position is taken on the basis of sufficient evidence.	1 2 3 4 5
17	Scientific questions are answered by observing things.	1 2 3 4 5
18	Good scientists are willing to change their ideas.	1 2 3 4 5
25	Scientists must report exactly what they observe.	1 2 3 4 5
3-B	To operate in a scientific manner one needs to know what other scientists think. One needs to know all the scientific truths and to be able to take the side of other scientists.	1 2 3 4 5
3	It is useless to listen to a new idea unless everybody agrees with it.	1 2 3 4 5
5	If one scientist says an idea is true, all other scientists will believe it.	1 2 3 4 5
32	Scientists should not criticize each other's work.	1 2 3 4 5
4-A	Science is an idea-generating activity. It is devoted to providing explanations of natural phenomena. Its value lies in its theoretical aspects.	1 2 3 4 5
20	A scientist must have a good imagination to create new ideas.	1 2 3 4 5
21	Ideas are the important result of science.	1 2 3 4 5
28	Science tries to explain how things happen.	1 2 3 4 5

4-B	Science is a technology-developing activity. It is devoted to serving mankind. Its value lies in its practical users.	1 2 3 4 5
9	Electronics are examples of the really valuable products of science.	1 2 3 4 5
24	A major purpose of science is to produce new drugs and save lives.	1 2 3 4 5
31	A major purpose of science is to help people live better.	1 2 3 4 5
5-A	Progress in science requires public support in this age of science; therefore, the public should be made aware of the nature of science and what it attempts to do; the public can understand science and it ultimately benefits from scientific work.	1 2 3 4 5
6	Only highly trained scientists can understand science.	1 2 3 4 5
8	Most people are not able to understand science.	1 2 3 4 5
38	Scientific work is useful only to scientists.	1 2 3 4 5
6-A	Being a scientist or working in a job requiring scientific knowledge and thinking would be a very interesting and rewarding life's work. I would like to do scientific work.	1 2 3 4 5
1	I would enjoy studying science.	1 2 3 4 5
27	I would like to work with other scientists to solve scientific problems.	1 2 3 4 5
30	I may not make great discoveries, but working in science would be fun.	1 2 3 4 5
36	I would like to be a scientist.	1 2 3 4 5
40	Working in a science laboratory would be fun.	1 2 3 4 5
6-B	Being a scientist or working in a job requiring scientific knowledge and thinking would be dull and uninteresting; it is only for highly intelligent people who are willing to spend most of their time at work. I would not like to do scientific work.	1 2 3 4 5
13	The search for scientific knowledge would be boring.	1 2 3 4 5
14	Scientific work would be too hard for me.	1 2 3 4 5
22	I do not want to be a scientist.	1 2 3 4 5
37	Scientists do not have enough time for their families or for fun.	1 2 3 4 5
39	Scientists have to study too much.	1 2 3 4 5

APPENDIX D: Science Motivation Questionnaire

To the Respondent

Please put a thick ☒ for the most appropriate response when answering the questions.

Factors	Question number	Question (Item)	Always =5	Often =4	Sometimes =3	Rarely =2	Never =1
Factor1: Intrinsic motivation and personal relevance(10 questions)	22	I find learning science interesting.					
	1	I enjoy learning the science.					
	25	The science I learn has					

[illegible]

Factor4: career motivation (2 questions)		learn the science well.							
	5	If I am having trouble learning the science, I try to figure out why.							
	17	I think about how learning the science can help my career.							
Factor 5: grade motivation (5 questions)	10	I think about how learning the science can help me get a good job.							
	3	I like to do better than the other students on the science tests.							
	7	Earning a good science grade is important to me.							
	12	I expect to do as well as or better than other students in the science subject/ course.							
	15	I think about how my science grade will affect my overall grade point average/mark.							
	20	It is my fault, if I do not understand the science.							

APPENDIX E: Learning Strategies Questionnaire

To the Respondent

This questionnaire is part of a research work at Addis Ababa University, and it is developed to learn more about the learning processes used in the classroom. To gain an accurate understanding of these processes, it is critical that we learn from you about your approach to learning science.

All information you provide will be kept strictly confidential. Participation in this research is voluntary and you are free to discontinue at any time. However your experience and opinions are crucial to helping us understand teaching and learning from the learners' point of view. I would appreciate that you are taking your time to complete my questionnaire.

Thank you for your cooperation.

Part I: Personal Information

Subject: _____

School : _____

Teacher code: _____

Grade : _____

Please put ☒ mark for the most appropriate response when answering the questions.

Part II: Students' Learning Strategies

A. Strongly Disagree

B. Disagree

C. Undecided

D. Agree

E. Strongly Agree

		A	B	C	D	E
	In our class, we generally:					
1	Set our own learning goals (ex. Determine what we need					

Textbook Reading

- | | | | | | |
|---|---|---|---|---|---|
| 1. I formulate questions from a chapter before I begin reading. | 5 | 4 | 3 | 2 | 1 |
| 2. Before reading an assignment, I survey headings, bold print, italics, questions, summaries, etc. | 5 | 4 | 3 | 2 | 1 |
| 3. I try to get the meaning of new terms as I encounter them the first time. | 5 | 4 | 3 | 2 | 1 |
| 4. I formulate questions to answer as I read an assignment. | 5 | 4 | 3 | 2 | 1 |
| 5. I look for main ideas as I read. | 5 | 4 | 3 | 2 | 1 |
| 6. I am able to readily identify clarifying details under each main idea. | 5 | 4 | 3 | 2 | 1 |
| 7. I read a text book chapter more than once. | 5 | 4 | 3 | 2 | 1 |
| 8. I use a textbook study system such as SQ3R. | 5 | 4 | 3 | 2 | 1 |

Note-Taking

- | | | | | | |
|---|---|---|---|---|---|
| 9. I take notes as I read my text book assignments. | 5 | 4 | 3 | 2 | 1 |
| 10. I take notes in lectures. | 5 | 4 | 3 | 2 | 1 |
| 11. After taking notes, I review them before going on to something else. | 5 | 4 | 3 | 2 | 1 |
| 12. I rewrite lecture notes. | 5 | 4 | 3 | 2 | 1 |
| 13. I compare notes with one or more classmates to check completeness and accuracy. | 5 | 4 | 3 | 2 | 1 |

Memory

- | | | | | | |
|---|---|---|---|---|---|
| 14. I review notes more than once or twice for exams and quizzes. | 5 | 4 | 3 | 2 | 1 |
| 15. I use mnemonics. | 5 | 4 | 3 | 2 | 1 |
| 16. I use visuals in my notes such as sketches, mind maps, diagrams, charts, etc. | 5 | 4 | 3 | 2 | 1 |
| 17. I quiz myself over material that could appear on future exams and quizzes. | 5 | 4 | 3 | 2 | 1 |
| 18. I organize details to main ideas into numbered or lettered lists. | 5 | 4 | 3 | 2 | 1 |
| 19. I convert text and lecture material into my own words. | 5 | 4 | 3 | 2 | 1 |
| 20. I think about material that could be on exams and quizzes when I am not studying. | 5 | 4 | 3 | 2 | 1 |
| 21. I try to organize main ideas and details into some logical or meaningful order. | 5 | 4 | 3 | 2 | 1 |
| 22. I try to understand material in my notes as opposed to memorizing. | 5 | 4 | 3 | 2 | 1 |

Test Preparation

- | | | | | | |
|--|---|---|---|---|---|
| 23. I study with a classmate or group. | 5 | 4 | 3 | 2 | 1 |
| 24. When I don't understand something, I get help from classmates, tutors, instructors, etc. | 5 | 4 | 3 | 2 | 1 |
| 25. I do all homework assignments. | 5 | 4 | 3 | 2 | 1 |
| 26. I turn in all homework assignments on time. | 5 | 4 | 3 | 2 | 1 |

27. I can easily identify what I have learned and what I have not yet learned before I take a test.
28. I review notes for a class before I go to that class.
29. I read assigned material before I go to class.
30. I begin studying for an exam from the first week material is assigned or covered in lecture.
31. I review lecture notes soon after class.
32. I keep up to date on assignments and homework.
33. I eat well-balanced meals daily.
34. I exercise daily.
35. I have taken a learning skills class or attended learning skills workshops.

5	4	3	2	1
5	4	3	2	1
5	4	3	2	1
5	4	3	2	1
5	4	3	2	1
5	4	3	2	1
5	4	3	2	1
5	4	3	2	1
5	4	3	2	1

Concentration

36. I study where it is quiet when trying to learn and remember something.
37. I study for a length of time then take a short break before returning to studying.
38. I study in the same place.
39. I avoid cramming.
40. I have all my study equipment handy to my study place (pens, paper, calculator, etc.).
41. When I sit down to study, I tell myself that I intend to study.
42. I break larger tasks into smaller segments in order to complete a large assignment.
43. When the subject matter is not naturally interesting, I find ways to learn it anyway.
44. It is not difficult to pay attention in class.
45. I avoid studying in the evenings as much as possible.

5	4	3	2	1
5	4	3	2	1
5	4	3	2	1
5	4	3	2	1
5	4	3	2	1
5	4	3	2	1
5	4	3	2	1
5	4	3	2	1
5	4	3	2	1

Time Management

46. I use a calendar book for recording daily and weekly upcoming academic and personal activities.
47. I use lists such as daily "to do" lists, priority lists, assignment lists, etc. to organize academic and personal activities.
48. I set up a master schedule of fixed monthly activities such as work, club meetings, etc.
49. I write out short-term and long-term academic goals.
50. I start papers and projects way before they are due.
51. I study 2 hours for every hour I am in class.

5	4	3	2	1
5	4	3	2	1
5	4	3	2	1
5	4	3	2	1
5	4	3	2	1
5	4	3	2	1

APPENDIX G: Documentary Analysis Rating Form

Title: _____ Grade: _____
 Subject Area: _____ No. of pages: _____
 Copyright Year: _____
 Type document: _____

Instruction: Read the documents page by page carefully and rate it along each evaluation criterion by encircling the appropriate number. For a rating below 4, write your comment/justifications on each evaluation criterion. If an evaluation criterion is not applicable, the document is rated 3 on said criterion. Attach extra sheets if necessary. Your report must be completed in ink. Please write legibly. See the annex for content evaluation summary form.

Factor 1: Appropriateness of Material

Using a 1 to 4 rating scheme, with 4 as the highest and 1 the lowest, check appropriateness of material on the following items:

1. Content is appropriate to the learner's grade level.	4	3	2	1
2. Vocabulary and length of sentences are suitable to target learners	4	3	2	1
3. Materials takes into account diversity of cultural, religious, economic and family backgrounds of target learners	4	3	2	1
4. Sentence, and paragraph structures are appropriate, varied, and interesting to target users	4	3	2	1
1. Treatment of gender in terms of roles, occupations and contributions in the text and illustrations of the textbook is balance	4	3	2	1
2. Material encourages integration of positive values and is mindful health and safety of the learners.	4	3	2	1
3. Text, visuals, illustrations, layout, and design are interesting and suitable to the target learners.	4	3	2	1
4. There is consistently good use of transition devices to focus on the main topics and signal a change of topic	4	3	2	1

Factor 2: Presentation and Organization of Material

1. Topics covered are logically presented throughout the material.	4	3	2	1
2. Units/chapters are arranged from simple to complex, from observable to abstract	4	3	2	1
3. Units/chapters contain useful introductions, reviews, summaries, and other devices that facilitate smooth progression from one lesson to another.	4	3	2	1
4. Development of lessons in the material allows review, comparison Review, comparison constructivist conceptual change, and integration with previous lessons.	4	3	2	1
5. Material promotes development of higher cognitive skills such as critical thinking, creativity, learning by doing, problem solving, validation of concepts conceptual change, and other similar skills.	4	3	2	1
6. Organization of material allows use of various types of constructivist conceptual change teaching and learning strategies to meet individual differences	4	3	2	1
7. Document layout and design are interesting, attractive, and suitable to the learners.	4	3	2	1
8. Layout and text organization (i.e., size of letters, choice of font, use of boldface and italics etc.)	4	3	2	1
9. Visuals (illustrations, photographs, maps, charts, graphs, etc.) are relevant to the text.	4	3	2	1
10. Visuals are used to facilitate understanding and conceptual	4	3	2	1

change.

11. Visuals are consistly clear in content, concept and detail.	4	3	2	1
12. Text has an adequate and useful gbssary of terms.	4	3	2	1
13. Material provides useful measures and information to help the teacher evaluate learner's progress in mastering the target competencies.	4	3	2	1
14. Material uses constructivist conceptual change strategies that allow or fuller development of social skills such as striving for excellence, being responsible, and working harmoniously with others.	4	3	2	1
15. There is logical and smooth flow of ideas and activities: a) Within a lesson b) From lesson to lesson	4	3	2	1
16. Lessons, instructions, exercises, questions, and activities are clear to the target user	4	3	2	1
17. Material provides useful measures and information to help the teacher evaluate learner's progress in mastering the target competencies.	4	3	2	1

Total Score: _____

Factor 3: Teacher's Guide(TG) and Curriculum Guides (CG)

1. The materials in the TG & CG correspond with the materials in the Text Book	4	3	2	1
2. All units/chapters have specific attainable, and measurable learning objective.	4	3	2	1
3. Lessons are developed using a variety of teaching methods including constructivist methods, learning activities which faster conceptual change, and authentic evaluation measures.	4	3	2	1
4. Teaching methods, learning activities, and evaluation measures are congruent with learning objectives.	4	3	2	1
5. TG & CG provide review of prerequisite, skills where needed	4	3	2	1
6. TG & CG includes rationales, alternative teaching approaches and additional remedial and enrichment materials	4	3	2	1
7. Time allotment in the TG & CG is sufficient to develop lessons in the TX within the corresponding number of school/semester days.	4	3	2	1
8. The resources mentioned in the TG & CG are sufficient and available in schools to develop lessons in the TX in order to bring about conceptual change.	4	3	2	1

Total Score: _____

Factor 4: Accuracy and Up-to-datedness of Information

1. Conceptual errors
2. Factual errors
3. Grammatical errors
4. Computational errors
5. Obsolete information
6. Other errors such as errors in illustrations, diagrams, pictures, maps, graphs, and tables

Annex

Reference code: _____ Summary for (please check) TX - TG

Subject: _____ Grade: _____

Note: For each instance regarded as a serious error (ex. Conceptual errors, factual errors, conflicting facts), assign 5 elements. For other instances of mistakes regarded as relatively minor, assign 2 elements. When the total elements is equal to greater than 50, major revision is required.

☐ Minor Revisions

Major Revisions

261

I/we certify that this evaluation report and recommendation are my/our own and have been made without any undue influence from others.

Evaluators: _____

Signature (s): _____

Date: _____

APPENDIX H: Class Room Observation and Analytic Protocol

Observation date: _____ Time: Start: _____

End: _____ School: _____ District: _____

Teacher: _____

Part one: The lesson

Section A: Basic Descriptive Information

1. Teacher Gender: ☐ Male ☐ Female
2. Subject observed ☐ physics ☐ chemistry
3. Lesson Title: _____
4. Grade level: _____ Class period: _____
5. Students: _____ Number of males _____ Number of females _____
6. Receive/collect copies of instructional materials: ☐ ☐ No, Explain

Section B: Purpose of the lesson

1. According to the teacher, the purpose of this lesson was:
2. Based on time spent, the focus of this lesson is best described as: (check one)
 - ☐ Almost entirely working on the development of /factors/ vocabulary
 - ☐ Mostly working on the development of /factors/vocabulary but working on same science concepts
 - ☐ About equally working on/facts/vocabulary and working on science concept
 - ☐ Mostly working on science concepts, but working on some /facts/vocabulary
 - ☐ Almost entirely working on science concepts

Section C: Lesson Ratings

Rate each of a number of key indicators in five different categories: 1 (not at all) to 5 (to a great extent). Use your "Ratings of Key Indicators" to inform your "Synthesis Ratings". It is important to indicate in "supporting Evidence for Synthesis Ratings" what factors were most influential in determining your synthesis ratings and to give specific exam. Plus and /or quotes to illustrate those factors.

If any one lesson is not likely to provide evidence for every single indicator; use 6, "Don't know" when there is not enough evidence for you to make a judgment. Use 7, "N/A" (not Applicable) when you consider the indicator inappropriate given the purpose and context of the lesson. This section also includes ratings of the likely impact of instruction and a capsule rating of the quality of the lesson. **2=somehow; 3=good;4=very good.**

I. Design

A	Rating of key Indicators	Not at all				To A great extent	Don't know	N/A
		1	2	3	4	5	6	7
1	The design of the lesson incorporated tasks, roles, and interactions consistent with investigative science							
2	The design of the lesson reflected careful planning and organization							
3	The instructional strategies and activities used in this lesson reflected attention to students' experience, preparedness, prior knowledge, and/or learning styles							
4	The resources available in this lesson contributed to accomplishing the purposes of the instruction.							
5	The instructional strategies and activities reflected attention to issues of access equity, and diversity of a students (e.g.), cooperative learning, language – appropriate strategies/materials							
6	The design of the lesson encouraged a collaborative approach to learning among the students							
7	Adequate time and structure were provided for “sense-making”							
8	Adequate time and structure were provided for wrap-up							
9								

B. Synthesis Rating

1	2	3	4	5
Design of the lesson not at all reflective of best practice in science education	Somehow good	good	Very good	Design of the lesson extremely reflective of best practice in science education

C. **Supporting Evidence for Synthesis Rating**

Provided a brief description of the nature and quality of this component of the lesson, the rationale for your synthesis rating, and the evidence to support that rating. _____

2=some how; 3=good;4=very good.

II. **Implementation**

A	Rating of key Indicators	Not at all				To A great extent	Don't know	N/A
		1	2	3	4	5	6	7
1	The instructional strategies were consistent with investigative science.							
2	The teacher appeared confident in his ability to teach science							
3	The teacher's classroom management style/strategies enhanced the quality of the lesson							
4	The pace of the lesson was appropriate for the developmental levels/needs of the students and the purpose of the lesson							
5	The teacher was able to "read" the students' level of understanding and adjusted instruction accordingly							
6	The teacher's questioning strategies were likely to enhance the development of student conceptual understanding/problem solving (e.g., emphasized higher order questions, appropriately used "wait time" identified prior conceptions and misconceptions)							
7								

❖ We anticipate that these indicators should be rated 1 – 5 for nearly all lessons. If you rated any of these indicators 6 or 7 please provide an explanation in your supporting evidence below. _____

Synthesis Rating

1	2	3	4	5
---	---	---	---	---

Implementation of the lesson not at all reflective of best practice in science education	Somehow good	good	Very good	Implementation of lesson extremely reflective of best practice in science education
--	--------------	------	-----------	---

C. Supportive Evidence for Synthesis Rating

Provide a brief description of the nature and quality of this component of the lesson, the rationale for your synthesis rating, and the evidence to support that rating. (If available, be sure to include examples/quotes to illustrate ratings of teacher questioning (A6). -----

2=somewhat; 3=good; 4=very good.

III. Science Content

A	Rating of key Indicators	Not at all				To A great extent	Don't know	N/A
		1	2	3	4	5	6	7
→1	The science context was significant and worthwhile							
→2	The science content was appropriate for the developmental levels of the students in this class							
→3	Teacher-provided content information was accurate							
→4	Student were intellectually engaged with important ideas relevant to the focus of the lesson							
5	The teacher displayed an understanding of science concept (e.g., in his dialogue with students)							
6	Science was portrayed as a dynamic body of knowledge continually enriched by conjecture, investigation, analysis, and/or proof/justification							
7	Elements of Science abstraction (e.g., symbolic representations, theory building) were included when it was important to do so.							
8	Appropriate connections were made to other areas of science, to other disciplines, and/or to real-world contexts							

9	The degree of "sense-making" of science content within this lesson was appropriate for the developmental levels/needs of the students and the purposes of the lesson.								
10									

- ❖ We anticipate that these indicators should be rated 1 -5 for nearly all lessons. If you rated any of these indicators 6 or 7, please provide an explanation in your supporting evidence below.

B. Synthesis Rating

1	2	3	4	5
Science content of lesson not at all reflective of current standards for science education	Somehow good	good	Very good	Science content of lesson extremely effective of current standards for science education

C. Supportive Evidence for Synthesis Rating

Provide a brief description of the nature and quality of this component of the lesson, the rationale for your synthesis rating, and the evidence to support that rating. (If available, be sure to include examples/quotes to illustrate ratings of quality of content (A1, A2, A3), intellectual engagement (A4), and nature of "sense-making" (A9).) -----

----- Are students in this class by level of ability?
(Darken one oval.) Yes No

2. Which of the following best describes the ability of the students in this class relative to other students in this school? (Darken one oval.)

- Fairly homogeneous and low in ability
- Fairly homogeneous and average in ability
- Fairly homogeneous and high ability
- Heterogeneous, with a mixture of two or more ability levels

IV. Classroom culture

A Rating of key Indicators		Not at all				To a great extent	Don't know	N/A
		1	2	3	4	5	6	7
1	Active participation of all was encouraged and valued.							
2	There was a climate of respect for students' ideas, questions, and contributions.							
3	Interactions reflected collegial working relationship among students (e.g., students worked together, talked with each other about the lesson).							

4	Interactions reflected collaborative working relationships between teacher and students.								
5	The climate of the lesson encouraged students to generate ideas, questions, conjectures, and/or propositions.								
6	Intellectual rigor, constructive criticism and the challenging of ideas were evident.								
7									

- ❖ We anticipate that these indicators should be rated 1 - 5 for nearly all lesson. If you rated any of these indicators 6 or 7, please provide explanation in your supporting evidence below.

B. Synthesis Rating

1	2	3	4	5
Classroom culture interfered with student learning	Somehow good	good	Very good	Classroom culture extremely facilitated the learning of all students.

C. Supportive Evidence for Synthesis Rating

Provide a brief description of the nature and quality of this component of the lesson, the rationale for your synthesis rating, and the evidence to support that rating. (If available, be sure to include examples/quotes to illustrate ratings of active participation (A1), climate of respect (A2), and intellectual rigor (A6). While direct evidence that reflects particular sensitivity or insensitivity toward student diversity is not often observed, we would like you to document any examples you do see)

Section D. Lesson Arrangements and Activities

- a) Time spent on instructional activities? _____ Minutes
 - b) Time spent on non-instructional activities? _____ Minutes

Give Description

c) Check here if period):

2. What percent of instructional time was spent in each of the following arrangements?

- a. Whole class _____ %
- b. Pairs/small groups _____ %
- c. Individuals _____ %

Section E. Overall Ratings of the Lesson

1. Likely impact of instruction on student's understanding of science

While the impact of a single lesson may well be limited in scope it is important to judge whether the lesson is likely to help move students in the desired direction. For this series of ratings, consider all available information (i.e., your previous ratings of design, implementation, content, and classroom culture and the interview with the teacher) as you assess the likely impact of this lesson. Elaborate on ratings with comments in the space provided.

Select the response that best describes your overall assessment of the likely effect of this lesson in each of the following areas.

		Negat ive Effect		Mixed or neutra l Effect		Positive Effect	Don't know	N/A
		1	2	3	4	5	6	7
a	Students' understanding of science as a dynamic body of knowledge generated and enriched by investigation.							
b	Students' understanding of important science concepts							
c	Students' capacity to carry out their own inquiries							
d	Student's ability to apply or generalized skills and concepts to other areas of science, other disciplines, and/or real-life situations.							
e	Students' self-confidence in doing science							
f	Students' interest in and/or appreciation for the discipline.							

Comments:

APPENDIX I: Example Lesson Plans for Experimental Group Utilizing SCSMCC-based
RPC method

Lesson Plan 1: The First Law of Thermodynamics from Physical Thermodynamics Unit 1 of Grade
12 Physics Using SCSMCC-based RPC

Class _____ Instructor _____ Date _____
 Topic _____ Length of Time of Lesson: _____

Pedagogical Purpose

"Students should be encouraged to develop affective attributes of scientists at work; such as: respect for evidence, tolerance of uncertainty, intellectual honesty, creativity, perseverance, cooperation, curiosity and a desire to understand. ... (initiate and plan an experiment.) Students will be expected to demonstrate an understanding... of the central role of evidence in the creation and accumulation of knowledge, and the ways proposed theories may be supported, modified and refuted." (Adapted from *Alberta learning, 1994, pp: 3-7*).

Scientific Purpose

To understand heat, internal energy, and work concepts along with their relationships.

Instructional Objectives

To relate the first law of thermodynamics to the law of conservation of energy
 To distinguish internal, work and heat on the basis of whether they are process or state functions
 To apply the first law of thermodynamics in specific contexts or situations.

I. Introduction

Teacher presents/introduces two categories of conceptions. Valid and invalid conceptions for students to take position on.

Teaching Method: Reasoned Persuasive Collaboration (RPC) based on SCSMCC

Category 1	Category II
1. Heat is a material substance but not a process of transfer of thermal energy.	1. Heat is not a material substance but a process of transfer of thermal energy.
2. Heat is a form of energy but not a process of transferring thermal energy.	Heat is not a form of energy but a process of transferring thermal energy.
3. Temperature and pressure are process (path) functions but heat and work are state functions.	Temperature and pressure are state (point) functions but heat and work are process functions.
4. Heat and work are dependent means of energy transfer.	4. Heat and work are independent means of energy transfer.
5. The amount of internal energy in a substance does not determine its state.	5. The amount of internal energy in a substance determines its state.

Students are required to take position as to which of the above two categories is the scientifically valid conception first, individually and then in small groups which will then lead to whole class discussion and consensus. Time required to write the categories on the board is 3 minutes.

II. Exploration of Concepts

Teacher asks the students to jot down their reasoning on individual basis to select the correct category for each of the 1 to 5 conceptions (5 minutes). Teacher asks the students (pre-planned mixed ability group:

one high achiever, two medium achievers, and one low achiever) to share ideas and arrive at consensus (3 minutes).

III. Conceptual Development

Teacher invites all of the groups which selected their spokesperson to involve in whole class discussion and show why Category II is the most acceptable scientific position and s/he elaborates on scientific conceptions using his short and precise note(5 minutes).

IV. Extending Concepts and Overcoming their Original Misconceptions

Individual students critically reflect on what has been so far learned and jot down most important points(7 minutes). Students rethink and correct their original position when their original position is not same as the one the class adopts. Teacher gives class work problems to see if deep conceptual understanding has been achieved which can first be tried individually and in case of difficulty involve group members. The group members reflect on the meaning of their solutions to problems. If the group members are unable to solve the problem in a class they should do it outside the class using extra resources leading to the second cycle of the spiral. The problems should require deep conceptual understanding (13 minutes).

V. Provision of Review Questions, Homework exercises, Home Projects, Class and Home Take Problems and Assignments, etc. (7 minutes). Example:

- 1) Why do we say that work is not a form of energy but a process of transferring energy from one form to another (kinetic energy to potential energy and vice versa)?
- 2) Why do we say that in any mechanism of transformation of energy, heat is the ultimate form of energy?
- 3) Is the total energy of the system the same as internal energy of the system?

List down your arguments using reasoning, evidence and justification. Students need to cite examples in order to extend/transfer concepts developed to other situations. In this way students arrive at conceptual change.

Resources which can be utilized: Internet and web resources, textbooks, commercial books, etc.

Lesson Plan 2: Enthalpy and Hess's Law from Chemical Thermodynamics Unit 3 of Grade 12 Chemistry Using SCSMCC-based RPC

Class _____ Instructor _____ Date _____
Topic _____ Length of Time of Lesson: _____

Pedagogical Purpose

"Students should be encouraged to developed affective attributes of scientists at work; such as: respect for evidence, tolerance of uncertainty, intellectual honesty, creativity, perseverance, cooperation, curiosity and a desire to understand. ... (initiate and plan an experiment.) Students will be expected to demonstrate an understanding... of the central role of evidence in the creation and accumulation of knowledge, and the ways proposed theories may be supported, modified and refuted." (Adapted from Alberta learning, 1994, pp: 3-7).

Scientific Purpose

To understand enthalpy and Hess's law concepts in the context of chemical reactions.

Instructional Objectives

- To understand the concept of enthalpy in the context of chemical reactions
- To use Hess's law to calculate enthalpy changes during chemical reactions
- To distinguish exothermic and endothermic reactions based on enthalpy changes

I. Introduction

Teacher presents/introduces two categories of conceptions. Valid and invalid conceptions for students to take position on.

Teaching Method: Reasoned Persuasive Collaboration (RPC) based on SCSMCC

Category I	Category II
1. Enthalpy is a process function	1. Enthalpy is a state function
2. Hess's law is not a consequence of the first law of thermodynamics.	2. Hess's law is the consequence of the first law of thermodynamics.
3. Lack of understanding of the concept of PV work has no influence on understanding of enthalpy.	3. Understanding of PV work enhances understanding of enthalpy.

Students are required to take position as to which of the above two categories is the scientifically valid conception first, individually and then in small groups which will then lead to whole class discussion and consensus. Time required to write the categories on the board is 3 minutes.

II. Exploration of Concepts

Teacher asks the students to jot down their reasoning on individual basis to select the correct category for each of the 1 to 5 conceptions (5 minutes). Teacher asks the students (pre-planned mixed ability group: one high achiever, two medium achievers, and one low achiever) to share ideas and arrive at consensus (5 minutes).

III. Conceptual Development

Teacher invites all of the groups which selected their spokesperson to involve in whole class discussion and show why Category II is the most acceptable scientific position and s/he elaborates on scientific conceptions using his short and precise note (5 minutes).

IV. Extending Concepts and Overcoming their Original Misconceptions

Individual students critically reflect on what has been so far learned and jot down most important points (7 minutes). Students rethink and correct their original position when their original position is not same as the one the class adopts. Teacher gives class work problems to see if deep conceptual understanding has been achieved which can first be tried individually and in case of difficulty involve group members. The group members reflect on the meaning of their solutions to problems. If the group members are unable to solve the problem in a class they should do it outside the class using extra resources leading to the second cycle of the spiral. The problems should require deep conceptual understanding (13 minutes).

V. Provision of Review Questions, Homework exercises, Home Projects, Class and Home Task Problems and Assignments, etc. (7 minutes). Example:

- 1) How can you determine whether a reaction is endothermic or exothermic based on enthalpy change?
- 2) How can you determine whether a reaction is endothermic or exothermic based on changes of Gibbs free energy?
- 3) Show correct inequalities as >0 or <0 for each of ΔH , ΔS , and ΔG in the case of :
 - a) Exothermic reaction and
 - b) Endothermic reaction

List down your arguments using reasoning, evidence and justification. Students need to cite examples in order to extend/transfer concepts developed to other situations. In this way students arrive at conceptual change.

Resources which can be utilized: Internet and web resources, textbooks, commercial books, etc.

APPENDIX J: Interviews with Secondary Chemistry and Physics Curriculum Experts at the Ministry of Education

Both Chemistry expert (E_1) and Physics expert (E_2) gave their views on selected questions I forwarded to them. I organized their response to similar questions consecutively and reflected on them using my documentary analysis results and my field experiences. The interviews were transcribed (recorded) and reflected on as follows.

Question 1. How do you determine the content/subject matter to be used in secondary school Chemistry/Physics Curriculum?

E_1 : "We select the content of secondary school Chemistry on the basis of minimum learning competency."

E_2 : "Content/subject matter is determined by competencies prepared earlier. First, we have to prepare objectives and categorize objectives, and then syllabus is produced. We browse and see international experiences, but we do not try to copy instead adapt it to our context."

Reflection: In the TG and CG and even text book, I did not come across such phrase as "minimum learning competency". The minimum learning competency required by each learner should have been stated besides learning objectives. Why not we demand highest standards rather than minimum standard of achievement?

Question 2. How you determine the purposes of secondary science curriculum?

E_1 : "The purpose of science/Chemistry curriculum is based on the educational policy of the country."

E_2 : "The purpose is in line with the educational policy of the country."

Reflection: The ETP (1994) did mention about learner-centered methods as a future for science learning, but it did not envisage or made no mention of constructivist curriculum as the most appropriate curriculum for science learning. And how can it be the source of purpose for the so-called constructivist curriculum.

Question 3. What is the best learning theory on which you based your secondary Chemistry Chemistry/Physics curriculum development?

E₁: "The newly revised curriculum is based on constructivist learning theory."

E₂: "The new Physics curriculum is based on constructivist learning theory."

Reflection: Why not eclectic curriculum, which takes into account the best elements of all the four learning theories. Can we really abandon behaviorism, cognitivism, and multiple intelligences? In practice, the curriculum developed was not purely constructivist learning theory-based as we have seen in the documentary analysis section.

Question 4. Why did you select the constructivist learning theory?

E₁: "Constructivist learning theory is modern and involves learners in the teaching/learning process. That is why it is selected by the Ministry of education."

E₂: "The ministry of education selected this kind of curriculum. It was a top-down approach and I personally believe that it is right kind of theory for Physics teaching."

Reflection: Both top-down and bottom-up curriculum development should have been better. Need assessment of all stakeholders should have been made before we really decide the kind of curriculum that best suits our context in a top-down approach.

Question 5. What do you think is the drawbacks or pitfalls of constructivist curriculum?

E₁: "All theories have their own draw backs and merits. The drawbacks/pitfalls are, I think, if the teachers are not well trained in the implementation of constructivist curriculum it may not achieve its aims as intended. We only recently, the first semester of 2003 E.C or 2010 G.C, dispatched the text books, curriculum guides and teacher guides, but the training was not given ahead of its implementation."

E₂: "As it is a newly tried theory in our curriculum, I cannot say or conclude that it has drawbacks/pitfalls. But before it was sent to school, training workshops should have been given to school teachers."

Reflection: Most science teachers feel that constructivist strategies are simply time-consuming and they have problem covering syllabus on time. In the era of knowledge explosion this is a huge problem as the learners are becoming ignorant of some topics which were not covered.

Question 6. What is its advantage?

E₁: "Students work by themselves, when assisted well get more knowledge than in the traditional curriculum."

E₂: "The merit is learning by doing. Learners should construct their knowledge and draw meaning from learning material by themselves, so this is one advantage."

Reflection: Constructivist curriculum/instruction have their merit as the students are encouraged not to take the learning content for granted or as a finished product. It encourages learner development of

content using participatory approach, in addition to personal knowledge construction. My SCSMCC model advocates a balanced knowledge construction both individually and in groups.

Question 7. What are the pitfalls of traditional (content only) science curriculum/instruction? What are its advantages, if any?

E₁: "Teachers are source of knowledge and students are recipients of knowledge. Hands on , minds on , hearts on, etc. are not used in this curriculum. The rote learning method by students is not effective in producing a fruitful citizen."

E₂: "The pitfalls are: teacher is authoritarian, students are not engaged in teaching learning process. They are merely, and passively receive knowledge, so this is not a good way of learning. It has one advantage, as it is fast it can help cover the syllabus on time."

Reflection: The traditional curriculum considers learners as cups to be filled with knowledge. Learners are passive recipients of knowledge. They take learning content for granted or as a finished product. They do not question, doubt or critically analyze the content they are learning. Such kind of learning is not transferrable to real-world contexts and solves ill-structured problems.

Question 8: What kinds of instructional strategies you mostly choose for your Chemistry/Physics curriculum?

E₁: "Active learning strategies are selected. Student-centered activities and methods which involve our learners are usually selected. We consider the time consuming nature of active learning methods, and we tried to reduce the content load of the curriculum in order to cope up with time constraint or coverage of syllabus. We removed repetitions, and made our teachers skillful in planning."

E₂: "The choice depends on content. Mostly we use active learning methods such as group discussion, questioning, brainstorming and the like."

Reflection: As active learning methods are time-consuming, why not use the combined methods of teaching. Major science concepts should be taught using constructivist strategies for deep understanding. Minor science concepts should be taught using traditional methods as these are fast and help cover the syllabus on time. No method is complete in every sense.

Question 9. What kinds of assessment techniques you choose for the Chemistry/Physics curriculum?

E₁: "Obviously continuous assessment is part and parcel of teaching-learning process. They have to be assessed throughout the course of their learning. Assessment is not for students only but as a feedback for the teacher (self-assessment) himself. Assessment is both a means of teaching and evaluation."

E₂: "Formative and summative assessments are used. Continuous assessment is emphasized and mostly used because the teacher needs to know what kinds of learning difficulties students have at each phase of teaching/learning process."

Reflection: Authentic assessment techniques which employ continuous assessments should be used in the new curriculum. If traditional assessments are used, they are not simply compatible with the new constructivist curriculum.

Question 10: Do you have enough resources to carry out constructivist curriculum at your schools for your respective subjects?

E₁: "Resources were considered during revision of our curriculum. International consultants who came to assist as during development of the curriculum helped identify instructional strategies which work with limited resources and also internet resources were used to identify international experiences."

E₂: "Some schools have enough resources and in some others there are shortages. An attempt has been made to alleviate shortage of materials using locally available materials and prepare them as in science kits."

Reflection: If resources are not uniformly available across the schools, justice has not been made by requiring them to sit for the same national exam. A curriculum prepared without necessary inputs will not be implemented as intended.

Question 11. What proportion of factual, procedural and conceptual knowledge is represented in the curriculum?

E₁: "I cannot tell you the exact figure. But now we tried to integrate all of factual, conceptual and procedural knowledge."

E₂: "In the new science curriculum we incorporated the three kinds of knowledge: factual, procedural, and conceptual. In proportion the conceptual is the highest, followed by procedural, and by factual. We focus on facts then connect to concepts and then concepts help computational knowledge."

Reflection: The text books as shown in the documentary analysis section lack a clear balance of the three types of knowledge. The examples, activities, and exercises are mostly going for 'one right numerical answer' rather than divergent questions with many possible answers in conceptual science.

Question 12. What areas of the current science curriculum need to be changed?

E₁: "We really do not know, because feedback has not been received from schools. It is only in October 2010 we released the new curriculum to schools. The text books reached the schools in December 2010, so we do not know what areas of it need to be improved."

E₂: "This is based on feedback we get from schools. And it is premature to say that this or that part need to be revised."

Reflection: The new curriculum is not clearly situated. It is based on, for example, material resources which are mostly not available in schools. For this, I think, we do not need to wait for feedback from schools to make adjustments.

Question 13. Does the current curriculum has the power to handle students' misconceptions and student learning difficulties?

E₁: "Yes, because we tried to clarify the concepts very well. The textbooks are smart and colorful. And very sound teacher guides explain everything."

E₂: "Yes, it does, there are many misconceptions in Physics. We tried to minimize such misconceptions by providing clear ideas. In heat and thermodynamics, students consider heat as a substance not as a form of energy transfer."

Reflection: The documentary analysis section has shown that not enough misconceptions have been identified in the teacher guides and text books along with means of overcoming them. No conceptual change models are tried in the new curriculum.

Question 14. What kind of alternative science curriculum you suggest if the current one is incompatible with the challenges stated above?

E₁: "It depends; we do not have feedbacks from the current one. When we have the feedback that the newly introduced curriculum does not work we will try another one."

E₂: "I have no answer for this question."

Reflection: The experts did not have any contingency curriculum, if the newly introduced curriculum turns out to be a failure.

APPENDIX K: Interviews with Grade 12 Chemistry and Physics Students on Thermodynamics Concepts

After the treatments, I selected five students for interview on their Thermodynamic understandings. Students S₄ and S₅ were selected from the experimental group, students S₁ and S₂ were selected from the comparison group, and student S₃ was selected from a section outside the two groups. Students were selected with the help of their teachers and the teachers selected them based on their classroom performance and assumed to be equivalent on their abilities. The experimental group students answered almost 50% of the questions. The comparison group students answered almost 30% of the questions and the one outside the two sections/groups answered about 20% of the questions. I organized their response to similar questions in a serial manner and finally reflect on them. The interviews were transcribed (recorded) as follows.

Question 1. Do you think heat and temperature are equivalent?

S₁: "No! Because heat is one form of energy which can flow from high temperature region to low temperature region. So the flow heat is due temperature difference."

S₂: "They are different because temperature is the measure of average kinetic energy of molecules but heat is energy transfer between system and surrounding."

S₃: "Heat is a measure of energy where as temperature is a measure of hotness."

S₄: "Temperature is related to the average kinetic energy of molecules, but heat is a measure of energy related to an increase in kinetic energy of molecules."

S₅: "Heat energy is transferred between a system and its surrounding as a result of a difference in their temperatures. Temperature is generally a measure of average random kinetic energy of particles."

Reflection: Except student S₃, the other students have roughly clear scientific conception of heat and temperature. Student S₁, clearly defined heat but not the temperature.

Question 2. Do you think addition of energy as heat always increases the temperature of a body?

S₁: "Generally, yes! Because we know that $Q = mc\Delta T$. From this heat energy is directly proportional to temperature difference. So, addition of heat increases the temperature of a body."

S₂: "Yes! But when equilibrium is reached between system and surrounding, the temperature remains constant."

S₃: "Yes! The addition of heat always increases the temperature of a body."

S₄: "No! I don't think so. Often addition of heat increases the temperature of a substance but if the process is isothermal (slow process), there will be no increase in temperature and during phase change."

S₅: "This is not necessarily true because, for example, if you drop a hot needle into the lake, the temperature of the lake do not change, no matter how hot the needle is. Another justification is during phase transition, the temperature remains constant as heat energy is either added or removed."

Reflection: Students S₄ and S₅ have roughly clear scientific conception regarding answers to question 2, but S₁, S₂, and S₃ have not answered the question correctly. Meaning 60% of the respondents are wrong and 40% of them are right in this case. This shows that misconceptions are prevalent in Grade 12 science students.

Question 3. Is heat a 'process' or a 'state' property of any substance?

S₁: "Heat is a static property of a substance. We can say heat can flow but the heat we talk about is one form of energy which is found in a given body."

S₂: "It is a process of any substance."

S₃: "Heat is a path function, not a state property. Heat is path dependent but change in heat is a state function."

S₄: "Heat is not a state function that depends on initial and final states of the system. Heat depends on the path taken so it is a path function."

S₅: "Heat is a 'process' property which is totally dependent on the path which bring the process. It is similar to other property like work."

Reflection: Students S₄ and S₅ have clear scientific conception regarding Question 3 but students S₁, S₂, and S₃ are either totally wrong or partially wrong. For example, student S₃ is partially wrong while S₁ and

S_2 are totally wrong. Who knows if the author induced misconceptions described in documentary analysis section have played a role in student misconceptions reflected here.

Question 4. When a gas is compressed adiabatically ($Q=0$), what will happen to the temperature of the gas?

S_1 : "As a system is compressed without heat supply, the volume of the system decreases so the dispersed molecules per volume become near to each other so the heat of each molecule will be combined that lead to temperature change. So that the temperature of the system increases."

S_2 : "When gas is compressed, ΔV (change in volume) is negative and work is positive. And energy is gained by the system. Therefore, temperature increases since this process is endothermic."

S_3 : "When the gas is compressed adiabatically work is negative and internal energy (U) become positive. That means the temperature of an adiabatic compression increase. That is when internal energy increase, the temperature increase."

S_4 : "The temperature will increase because when work is done on a system, it leads to an increase in internal energy, as a result there will be an increase in temperature."

S_5 : "As a gas is compressed adiabatically ($Q=0$), the temperature of the gas will increase as it is observed in many heat engines."

Reflection: Except students S_2 and S_4 who tried to reason out based on the first law of thermodynamics, the other students have only partial answers which lack good justification for their response. The first law of Thermodynamics was not internalized properly as responses to these questions show.

Question 5: What are negative, positive, or zero work concepts in Thermodynamics?

S_1 : "Work is said to be negative if heat (or internal energy) of the system is lost and positive if the internal energy increases. And zero if no volume change occurs or if net work is zero."

S_2 : "Negative work occurs when gas expands and signifies that the system loses energy, and that this energy is transferred from system to the surroundings. Positive work results when gas is compressed and it occurs when system gains energy, and that energy is transferred from the surroundings to the system. Zero work is done on isochoric or isometric process when volume is constant."

S_3 : "Work is positive when constant pressure increases the volume. Work is negative when same pressure decreases the volume. For isochoric (isometric) process, there is no change in volume and the work done is zero."

S_4 : "The negative, positive and zero work concepts are used to represent the process (work done on system, by system or constant (no work done). Work is negative when work is done by the system and positive when work is done on a system. But it remains constant if there is no change in its volume."

S_5 : "...If there is an expansion of gases, then there will be a negative work done and if there is compression of gases then positive work done will be observed. ...A negative quantity of work signifies

that the system loses energy, and that is, energy is transferred from the system to the surroundings. And when the quantity of work is positive, energy is gained by the system."

Reflection: Students S_2 and S_4 have fully answered the question; Student S_3 did not complete the answer but had a good start. He did not answer the case of zero work. So the answers to this question are 50% right and 50% wrong. Still students have difficulty understanding the three types of work mentioned above.

Question 6. What happens to entropy, S , when a substance undergoes phase changes? (Solid to liquid to gas or vice versa).

S_1 : "The entropy gradually changes as the temperature of the body increases but suddenly changes during phase change. So $S_{\text{solid}} < S_{\text{liquid}} < S_{\text{gas}}$."

S_2 : "...Randomness increases from solids to liquids to gases. ...So entropy increases when solids change to liquids and liquids change to gases. The inverse of the above explanations is true when the phases change from gas to liquid and from liquids to solids because the entropy is decreasing."

S_3 : "...Entropy is a measure of randomness or disorder. ...In case solid changes (converts) to liquid there is an increase in entropy. ...When liquid changes to solid there is decreasing entropy. In case of liquid changes to gas there is increasing entropy. The reverse, gas to liquid a decrease in entropy. Similarly, for solid to gas there is an increase in entropy."

S_4 : "The entropy will change. This entropy increase for a spontaneous changes (naturally occurring) and will decrease for non-spontaneous processes as entropy is the quantity that measure the degree of disorder, it will increase or decrease depending upon the process which take place."

S_5 : "...Entropy is thermodynamic property of a system that is related to a degree of randomness or disorder. Solids are more ordered than liquids and gases are less ordered than liquids. And so from here we can conclude that entropy increases from solids to liquids and finally to gases."

Reflection: Except student S_4 , the other students have correctly answered regarding entropy changes during phase changes in either direction (solid to liquid to gas or vice versa). Students have a better understanding of the second law of thermodynamics than the first law of thermodynamics as we have seen in the above responses.

Question 7. Suppose you withdraw metal and wood from a refrigerator, the instant you withdraw them which one feels cold?

S_1 : "The metal feels cold the moment it is withdrawn. After one minute the metal feels less cold than the wood because of conductivity difference."

S_2 : "Metal conducts heat and the wood does not conduct heat that is the difference in feeling. Wood feels colder."

S_3 : "I think the metal feels colder the moment it is withdrawn because of its surface nature."

S₄: "...Since the metal loses heat faster than wood, the wood feels colder."

S₅: "The moment it is withdraw, I think, they have the same temperature. Only after sometime, the wood feels colder."

Reflection: Except student S₅, all the other students answered wrongly. Since wood and metal are insulator and conductor respectively, some students tried to reason out that metal would feel colder. Irrespective of their material property if they have stayed in the same environment for sufficiently longer time, they should share the same temperature. These shows how prevalent are misconceptions, in science learning.

Question 8. How does the knowledge gained in 'Physical Thermodynamics' helped you in 'Chemical Thermodynamics'?

S₁: "The ideas are similar but the authors used different symbols for the same formula in Physics and Chemistry. The difference with Chemistry is that in Chemistry we have Chemical reactions."

S₂: "Physics comes before Chemistry because thermodynamic ideas are first taught in Physics and then applied to Chemical reactions."

S₃: "When we are learning thermodynamics we are considering the system and surrounding in Physics but when we are studying thermodynamics in Chemistry we are applying it to Chemical reactions."

S₄: "The ideas or concepts we learned in 'Physical Thermodynamics' are almost similar to that of 'Chemical Thermodynamics', so it is easier to learn 'Chemical Thermodynamics' than 'Physical Thermodynamics'."

S₅: "'Chemical Thermodynamics' is the application of 'Physical Thermodynamics' to Chemistry. So learning thermodynamics first, before applying it to Chemistry is good."

Reflection: Even though their views slightly vary, all of the students have answered this question correctly. For example, student S₁, aired lack of horizontal integration in the use of symbols for the same formula in Physics and Chemistry which make learning a little bit more difficult. There is no correct answer for this question as it asks for opinion.

Question 9. What do you understand by the term 'enthalpy'?

S₁: "Enthalpy is the change in energy during Chemical reaction."

S₂: "Enthalpy is the energy that is either absorbed or released during a chemical reaction."

S₃: "Enthalpy change for a give reaction is calculated thermo-chemically. We use Hess' law to calculate the enthalpy change."

S₄: "Enthalpy change was not taught in Physics but in Chemistry. We calculated the change for both endothermic and exothermic reactions."

S₅: "We have some difficulty distinguishing endothermic and exothermic reactions for a given reaction. But we can calculate the enthalpy change using Hess's law."

Reflection: Enthalpy is the amount of heat absorbed or given off by the system at constant pressure. $H=U+PV$, or $\Delta H= \Delta U+P\Delta V$. All of the students have difficulty in correctly defining enthalpy. This could be due to, as S_4 noted, lack of instruction about enthalpy in Physical Thermodynamics (see documentary analysis about this topic in Chapter three).

Question 10. In the first law of thermodynamics, we have internal energy (U), work (W) and heat (Q) related. Which one is 'state' function and which ones are 'process' functions?

S_1 : "Internal energy (U) is state function but work(W) and heat(Q) are path functions."

S_2 : "U is state function because it depends on temperature. Work is path function and heat is a state function."

S_3 : "Heat is a state function, internal energy is state function, but work is path function."

S_4 : "Work is a state function, internal energy is state function, but heat is a path function."

S_5 : "Internal energy is state function, work is path function but heat is state function."

Reflection: Only student S_1 has answered this question correctly. 80% of the students have difficulty understanding the first law of thermodynamics, which shows that students' misconceptions are prevalent in the complex field of thermodynamics.

Question 11. What do you understand by the term internal energy (U)?

S_1 : "Internal energy(U) is all forms of energy the body possesses."

S_2 : "It is not the total energy of the system. There are cases but not always."

S_3 : "It is the sum of kinetic and potential energies of the system."

S_4 : "Internal energy is the total energy of the system when it is not interacting with the environment."

S_5 : "Internal energy is the sum of heat and work on a system."

Reflection: students S_1 , S_3 , and S_4 attempted to answer this question correctly. Student S_2 is closer but not exact and student S_5 are totally wrong. 40% of the students did not have the correct conceptions of internal energy (U). This shows that, as in all questions asked about concepts related to the first law of Thermodynamics, the first law is the most misconceived law compared to other laws in Thermodynamics.

APPENDIX L: Publication

Shimeles Assefa (2012). The Spiral Cognitive-Sociocultural Model of Conceptual Change. *Staff and Educational Development International*, 16(1), 71-91.

CONCEPTUAL DEFINITION OF TERMS

An integrated (holistic) model is a model that integrates all elements of the system along with their interconnections or interrelationships into an organic and unified whole.

A priori knowledge is knowledge that rests on a *a priori* justification. A *a priori* justification is a type of epistemic justification that is, in some sense, independent of experience or is result of pure reason.

A posteriori knowledge is knowledge derived from experience as opposed to a *a priori* knowledge.

Accommodation is forming new schemata or splitting off new schemata from existing schemata to accommodate new information.

Assimilation is enlarging schemata with new information.

Abstraction is mental activity or feedback involving the performance of operations.

Affection is behavior involving feelings, interest, values, attitudes, and maturation.

Application is putting knowledge to use in an unfamiliar or novel situation.

Conceptual Change is generally defined as learning that changes an existing conception. For example, students' experience a conceptual change in understanding that heat is not a substance. This shows a major shift in their understanding of the nature of heat. This shift or restructuring of existing knowledge and beliefs is what distinguishes conceptual change from other types of learning.

Concept Formation is a process by which a person learns to sort specific experiences into general rules or classes.

Concept is an idea generalized from particular and relevant experiences. It is also a mental construct that frames a set of examples sharing common attributes. Examples of concepts are heat, temperature, work, internal energy, enthalpy, magnetic poles, sound, light, etc.

Conceptual theme is a topic of study that includes a concept in the title. A conceptual theme frames a conceptually based study.

Conceptual understanding is the understanding of substantive or declarative concepts which include the facts, laws, theories and principles of science.

Cognitive equilibration is a state of mental satisfaction.

Cognitive disequilibrium is a state of mental uncertainty about the explanation of an occurrence.

Cognitive process is a mental process involving reasoning, perceiving, memorizing, imaging or representing, abstracting, etc.

Critical reflection is a 'look back' on experiences and a means of constructing knowledge. It is the process of analyzing, reconsidering and questioning experiences within a broad context of issues. Students are adding depth and breadth to the meanings by asking questions and relating meanings to spectrum of other issues.

Dualism is a philosophy that the mental and the physical or mind and body or mind and brain are, in some sense, radically different kinds of things. It contrasts with monism which is a philosophy that there is only one fundamental category and pluralism which is a view that there are many kinds of categories.

Deep understanding is an understanding that can be verified through application and public or expert verification. It is a kind of understanding in which two or more concepts are stated as a relationship or the "big ideas" are related to the critical concepts and topics of a study. Example: heat and temperature are not equivalent; electromagnetic waves differ only in frequency; etc.

Empiricism is a kind of philosophy which states that our sense experience is the ultimate source of all our concepts and knowledge and that knowledge could not extend beyond the realm of experience.

Enthalpy is a measure of the total energy of a thermodynamic system. It includes the internal energy, which is energy required to create a system, and the amount of energy required to make room for it by displacing its environment and establishing its volume and pressure. It is state function and extensive quantity.

Entropy is a measure of the disorder of a system. Whenever energy freely transforms from one form to another, the direction of transformation is toward a state of greater disorder and therefore toward one of greater entropy.

Epistemology is the branch of philosophy that studies about the nature and basis of knowledge.

Externalization is the process of expressing and verbalizing what is internalized. It is my equivalent of verbal thought or speech in Vygotsky's works.

Equilibration is the regulating process by which the individual continuously changes and develops.

Functional monism is a kind of monism that sees things in functional interdependence and as a unified whole.

Gain is the difference between post test and pre test or the difference between post administration of questionnaire and pre administration of questionnaire.

Heat is the energy that flows from a substance of higher temperature to a substance of lower temperature or energy transferred because of temperature difference.

Heat engine is a device that changes internal energy to mechanical work.

Internal energy is the grand total of all energies inside a substance or the total of all molecular energies, kinetic plus potential energy, internal to a substance or energy within a substance in any form.

Internalization is the process of making symbols, language, memories, and images as part of the mind.

Knowledge Structure Coherence is a characteristic feature of knowledge that has a high degree of coherence and connectedness(integration) in its conceptual structure. For example, scientific knowledge.

Knowledge transfer is defined as the process by which knowledge gained in one context affects the process of knowing in another context. For example, knowledge gained in physical thermodynamics affects the process of knowledge generation in chemical thermodynamics.

Learning is defined as the symmetrical (balanced) interplay between individual construction and social construction of knowledge in the context of this research. Hutchins (1995:290) defined learning as neither occurring inside an individual nor happens outside during participation. Learning is the adaptation of structure in one part of a complex system to organization in other parts. Some parts are re-organized inside the skin. The question of individual learning now becomes a question of how that which is inside a person might change overtime as a consequence of repeated interventions with these elements of cultural structure. This synergetic definition of learning is by far better than that offered by either the cognitivists or socio-culturalists.

Metaphor is a poetically or rhetorically ambitious use of words, a *figurative* as opposed to *literal* use.

Paradigm is defined in my context as a pattern of concepts.

Predictive power is the ability of a theory to correctly predict an outcome.

Perception is the process of being aware of something through the senses.

Problem-solving is any activity that requires students to apply their understanding in a new situation.

Procedural understanding is the understanding required in knowing how to do science. It is the understanding that requires application of skills and processes.

Principle is a generalization that is a truth which holds consistently through time. Principles are "laws" such as laws of thermodynamics and use no qualifying terms. Principles fall at the conceptual level of generalizations in the structure of knowledge.

Processes are complex performances drawing on a variety of skills. Process abilities develop within the individual and grow in sophistication overtime.

Rationalism is a philosophy that states our concepts and knowledge are gained independently of sense experience by pure reason.

SCSMCC-based Reasoned Persuasive Collaboration(RPC) is conceptually defined as a classroom teaching strategy that use in-depth critical analysis of learning content using reason, evidence, justification and argumentation individually and in groups and understanding of which is measured by both conceptual and procedural problem exams.

Skills are specific competencies required for complex process performance. Skills need to be taught directly and practiced in context. Example, study skills and research skills.

Socio-culturalism is a theory of learning that bases itself on cultural and social influences of knowledge generation.

Spiral is a plane curve that, in general, winds around a point while moving ever further from the point.
Examples: shell of snail, milky-way galaxy and on the hair of our heads.

Structure is mental organization or coordination in systematizing information. It may involve the interrelating of parts or schemata.

Temperature is a measure of the average kinetic energy per molecule in a substance.

Theory is a systematically organized knowledge applicable in a wide variety of circumstances, especially a system of assumptions, principles, and rules of procedure devised to analyze, predict, or otherwise explain the nature or behavior of specific phenomena.

Thermodynamics is the study of heat and its transformation to other forms of energy.

Traditional methods, in this research, are conceptually defined as those reported by instructors to make little or no use of CAP approaches, relying primarily on passive-student lectures, and understanding of which is measured by algorithmic/procedural problem exams.

Understanding is the ability to explain and interpret information within a given context and the ability to apply knowledge in solving problems.

Validity is a conclusion correctly deduced from evidence or appropriateness and meaningfulness of an instrument for a given measurement purpose.

Zone of proximal development is the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers. According to Vygotsky(1978), the only good learning is learning that occurs beyond the actual development level.

DECLARATION

I hereby declare that this dissertation is my original work and has not been presented for a degree in any other University, and that all sources of material used for the dissertation have been duly acknowledged.

Name: Shimeles Assefa Alemu

Signature: 

Date: September, 2012

I hereby declare that this dissertation is from the student's own work and effort, and all other sources of information used have been acknowledged. The thesis has been submitted with my approval as research advisor.

Name

Advisor: Amare Asgedom(PhD)

Signature

