Cooperative Pair Problem Solving: A teaching-learning strategy for tutorials in Mechanical Engineering Thermodynamics

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DECLARATION

I the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

24 October 2017

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There are two laws in thermodynamics. The first states that energy cannot be created or destroyed. One formulation of the second law states that on a molecular level the order in the universe decreases all the time. I hope that during teaching and learning, CPPS will save energy and result in more order and better understanding.

ABSTRACT

Cooperative Pair Problem Solving: A teaching-learning strategy for tutorials in Mechanical Engineering Thermodynamics

This study was conducted to find a solution to the problem of poor pass rates in the first introductory thermodynamics course that I teach, as well as to address the perception of students that the course is very demanding and the concepts difficult to understand. Using pair programming and pair problem solving as departure points, a cooperative teaching-learning strategy that can be implemented during problem-solving tutorials (CPPS) was developed. The procedure was developed to be suitable for large classes of a hundred students or more, but is also suitable for classes with fewer students.

A theoretical framework for CPPS was developed based on the social cognitive theory, the social constructivist theory, and the social interdependence theory.

To evaluate the success of CPPS, empirical data was collected using qualitative and quantitative methods. The qualitative methods used were interviews with students, a questionnaire with six open-ended questions completed by the student assistants, observer reports, the researcher's journal, and two open-ended questions in a student questionnaire. The quantitative methods consisted of a test written by the students assessing their conceptual understanding, a questionnaire with Likert-scale statements filled in by the students, and data over four years on academic performance.

It was found that the five elements of cooperative learning were successfully structured in CPPS. The procedure was well worth the effort of implementation for several reasons. It dramatically reduced the teaching load of the instructor during the tutorial due to peer instruction and active learning. The implementation of the procedure was made significantly easier by using a laptop for group formation and having the students submit their answers on a dedicated website using their cell phones. Attending CPPS tutorials improved students' academic performance, but had no effect on their conceptual understanding. Generally, students were positive about the procedure. Some did not like specific aspects at all, such as the fact that they could not choose their own partners. Others did not mind or even welcomed the opportunity to meet new people. An explanation for the difference in student attitudes towards working with strangers is proposed.

CPPS is a well-structured, easy to implement, cooperative teaching-learning strategy suitable even for large groups of hundred students or more in engineering-science problem-solving tutorials. CPPS creates an effective teaching-learning environment and results in a positive and cheerful atmosphere in class.

Key words: cooperative learning, problem solving, Thermodynamics, tutorials, large classes

OPSOMMING

Koöperatiewe Probleemoplossing in Pare: ’n Onderrig-leerstrategie vir tutoriale in Meganiese Ingenieurstermodinamika

Hierdie studie is onderneem ten einde ’n oplossing te vind vir die kwessie van lae slaagsyfers in die eerste inleidende termodinamika-kursus waarvan ek die dosent is, die persepsie van studente dat die kursus baie veeleisend is en dat die begrippe moeilik is om te verstaan. Paarprogrammering en paarprobleemoplossing is as vertrekpunte gebruik vir die ontwikkeling van ’n koöperatiewe onderrig-leerstrategie (KPOP) wat geskik is vir implementering tydens probleemoplossingstutoriale. Die prosedure is só ontwikkel dat dit toegepas kan word in groot klasse van ’n honderd of meer studente, maar ook so dat dit geskik is vir klasse waar daar minder studente is.

’n Teoretiese raamwerk vir KPOP is ontwikkel gegrond op die sosiale kognitiewe teorie, die sosiale konstruktivistiese teorie en die sosiale interafhanklikheidsteorie.

Ten einde die sukses van KPOP te evalueer, is empiriese data ingesamel met behulp van kwalitatiewe en kwantitatiewe metodes. Die kwalitatiewe metodes het bestaan uit onderhoude met studente, ’n vraelys met ses oop vrae wat studente-assistente voltooi het, waarnemersverslae, die navorser se joernaal sowel as twee oop vrae in ’n vraelys vir studente. Die kwantitatiewe metodes het bestaan uit ’n toets wat studente se konseptuele begrip geassesseer het, ’n vraelys met Likert-skaalstellings wat die studente voltooi het en vier jaar se data van akademiese prestasie.

Daar is bevind dat die vyf elemente van koöperatiewe leer suksesvol in KPOP gestruktureer kon word. Die prosedure was om verskeie redes die moeite werd om te gebruik. Dit verlig die onderriglas van die dosent tydens die tutoriaal aansienlik as gevolg van portuuronderrig en aktiewe leer. Die toepassing van die prosedure is heelwat vergemaklik deur ’n skootrekenaar vir groepvorming te gebruik en ’n webwerf waar die studente hulle antwoorde kon aflaai. Studente se akademiese prestasie is verbeter deur die bywoning van KPOP-tutoriale, maar bywoning van KPOP tutoriale het geen uitwerking op studente se konseptuele begrip gehad nie. Oor die algemeen was studente positief oor die prosedure. Sommige van hulle het ’n besliste afkeer gehad van spesifieke aspekte, veral die feit dat hulle nie hul eie maats kon kies nie, terwyl ander nie omgegee het nie of selfs die geleentheid verwelkom het om nuwe mense te ontmoet. ’n Verduideliking vir die verskil in studente se gevoelens jeens die feit dat hulle saam met vreemdelinge moes werk, word voorgestel.

KPOP is ’n goed gestruktureerde, maklik implementeerbare, koöperatiewe onderrig-leerstrategie wat ook geskik is vir groot groepe van ’n honderd of meer studente in probleemoplossingstutoriale van ingenieurswetenskappe. KPOP skep ’n doeltreffende onderrig- en leeromgewing en het ’n positiewe en aangename klasatmosfeer tot gevolg.

Sleutelwoorde: koöperatiewe leer, probleemoplossing, Termodinamika, tutoriale, groot klasse

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CHAPTER 1
INTRODUCTION

In this chapter, the important aspects of the study are introduced and briefly discussed. The detail discussion and motivations follow in the relevant chapters.

1.1 Background

Thermodynamics is an integral part of any mechanical engineering curriculum. At both universities where this study was conducted, a first introductory thermodynamics module is presented to students in their second year of study. In tests and examinations students must solve several generally well-defined problems with a single correct answer. The pass rate in these two introductory modules has generally been low compared to the other modules taken by the same students – and many students felt that Thermodynamics was difficult to understand and to pass. Several modules in the curriculum build on the foundation laid in the thermodynamics module. It is therefore also important that apart from passing tests and examinations, students also understand thermodynamic concepts introduced in this module.

At both universities where this research was conducted, the teaching strategy consists of morning lectures, as well as one problem-solving tutorial session (in the afternoon) per week. During tutorials students are given the opportunity to develop their problem-solving skills by solving several prescribed problems. However, prior to this study only a handful of students attended the tutorials at the university where I teach. Instead of spending the afternoon struggling to solve the problems, students who did not attend tutorials preferred to obtain solutions from students who already completed the tutorial. Furthermore, during course evaluations and in class, students complained that I did not do enough problems on the board. This passive student approach is also reported in the literature. Karimi and Manteufel (2012) reported that students increasingly got hold of the solution manual to prescribed end-of-chapter problems in the textbook. According to Detloff (2000) students demanded that as a lecturer he should do more problems in class.

Various approaches have been proposed as improvements to the traditional approach of lectures and tutorials. One of these approaches is inductive teaching, where students are first confronted with specific problems or observations. Once they understand the context and what knowledge is necessary to solve the problems, the theory is introduced (Felder & Brent, 2016). These inductive approaches include problem-based learning, project-based learning, and case-based learning (Prince & Felder, 2006). However, inductive teaching methods may not be the most appropriate approach for an introductory engineering-science module where the focus is on solving reasonably well-structured problems and inductive resources are scarce (Prince & Felder, 2007).

Permitting students to take a more active part in the learning process has been shown to be an effective teaching strategy (Freeman et al., 2014; Prince, 2004; Smith, Sheppard, Johnson, & Johnson, 2005). One such strategy is cooperative learning (CL). Roger and David Johnson of the University of Minnesota started their work on CL in the sixties, and have promoted CL as an alternative to individualistic and competitive learning. The advantages of CL over individualistic and competitive learning has been proven in numerous studies (Johnson, Johnson, & Johnson-Holubec, 2008).

Maceiras, Cancela, Urrejola, and Sanchez (2011, p. 13) implemented Jigsaw, a CL strategy in a course for final year students, and found that students “reach an understanding … far deeper” than merely listening to a lecturer. Zemke, Elger, and Beller (2004) applied CL in a Materials Science course and the students overwhelmingly indicated that it enabled them to master difficult material more easily. Detloff (2000) noted a significant improvement in student performance due to the implementation of CL in a computer and electronics engineering course.

Despite its proven advantages, CL is not implemented as widely as one would expect (Ahern, 2007; Smith et al., 2005). CL has definitive advantages, yet it comes at a price. Maceiras et al. (2011) mention that the initial preparation for CL required much more effort than the traditional approach. Detloff (2000) reports that he was tempted to abandon CL due to the large increase in preparation and evaluation time necessary, and that his resolve was taxed to the limit.

There may also be resistance to CL from students. The traditional lecture is probably the most common instructional strategy they have been exposed to in high school education (Ledlow, White-Taylor, & Evans, 2002). It seems that students are used to and comfortable with passively listening to the teacher and memorizing the information as a strategy to pass tests. Felder and Brent (2016, p. 243) note that students tend to resist procedures where they are expected to take more responsibility for their own learning than what they are used to. Resistance may also come from bad prior experience with group work. According to Baker and Clark (2010, p. 264) students specifically do not approve of an uneven distribution of workload.

The authors recommend that students should be taught to function in groups otherwise the outcome may be “resentment and frustration”. The implementation of CL in engineering does not seem to be a straightforward endeavour.

In the teaching of computer programming, a successful collaborative programming approach, pair programming, was developed (Williams, Kessler, Cunningham, & Jeffries, 2000). In pair programming two programmers work side by side using only one computer and collaborate on the design, algorithm and execution of the task (Williams & Upchurch, 2001). It draws on the principles of pair problem solving as introduced by Lochhead (1985). Mentz, Van der Walt, and Goosen (2008) suggested that cooperative learning principles should be incorporated into pair programming to render it a more effective teaching-learning strategy.

There exist similarities between problem solving in introductory thermodynamics modules and computer programming – both relies on the application of logic and the development of a problem-solution strategy to solve a wide variety of problems. Because of these similarities, it was decided to determine to what extent it would be possible to develop a procedure, based on the approach followed in pair programming, that was suitable for introductory thermodynamics tutorials.

1.2 Goal

In light of the background given in the previous paragraph, the purpose of this study was to develop an effective and viable cooperative pair problem-solving strategy for tutorials in the module Thermodynamics, based on pair programming (Williams & Kessler, 2003) and pair problem solving (Whimbey, Lochhead, & Narode, 2013) that incorporated the elements of cooperative learning (Johnson & Johnson, 2013). In this study, the envisaged problem-solving strategy is in short referred to as CPPS.

1.3 Theoretical and conceptual framework

In cooperative learning, students must work together and rely on each other to successfully reach a common goal. The model of CL developed by David and Roger Johnson (Johnson et al., 2008) contains five elements: positive interdependence; individual accountability; promotive interaction; development, and the appropriate use of teamwork skills, as well as regular assessment of team functioning.

The theoretical framework for the research in this study is based on the social cognitive theory, the social constructivist theory, and the social interdependence theory.

According to the social cognitive theory, three factors interact: behavior, personal factors, and environmental conditions. In the context of cooperative learning, a desired behavior is that students should cooperate, learn from, and help each other. An environment that promotes cooperation should therefore be created. An important environmental variable is the fact that the students work together in pairs. Other environmental factors were manipulated to strengthen the perception of students (a personal factor) that they needed to coordinate their efforts and rely on each other to solve the tutorial problems.

According to Johnson and Johnson (2013) the social interdependence theory is the most important theory dealing with cooperation. When the performance and success of one team member contributes to the success and performance of the other team member, it results in positive interdependence which tends to lead to promotive interaction: team members helping and facilitating the success of each other.

During learning, according to the constructivist view, the student is an active participant in the learning process and selects, re-organizes, and re-interprets information and experiences in order to make sense and give meaning to information and experiences. In other words, students construct their own knowledge (Ertmer & Newby, 2013). Social constructivism emphasises the role played by the interaction between people during constructivist learning. People learn by cooperating with other people on an equal footing, but also by being introduced to concepts already developed by society.

With this theoretical framework as background, and to reach the goal stated in paragraph 1.2, the research questions were formulated.

1.4 Research questions

The primary research question for this study was: How can a cooperative pair problem-solving strategy (CPPS) be designed for Mechanical Engineering Thermodynamics tutorials and how successful is its implementation? To answer this question, two aspects were considered.

The first aspect was the design of a strategy that can be implemented during the problem-solving tutorials in Thermodynamics. During tutorials students are given several prescribed problems to solve. The strategy should therefore create an environment in which students can develop their problem-solving skills. Furthermore, the strategy has to be suitable for students working in pairs.

To be a CL strategy, the five principles of CL must be structured in the strategy. Structuring in this context is more than expecting from students to take specific actions (such as group processing, one of the elements of CL), it also includes manipulating the environment to ensure that specific behavior ensues (such as promotive interaction, another element of CL), as well as the promotion of a specific perception (that students should rely on each other and coordinate their efforts).

The second aspect in answering the main research question comprised the evaluation of the success of CPPS. This was done by considering three aspects: (a) The extent to which students (and other role players) experienced the five elements of CL during CPPS. In other words, how successful was the structuring of the five elements? (b) The perceptions of the different role players of CPPS. In other words, how successful (apart from the structuring of the five elements) was CPPS according to the role players? For instance, is the procedure practical and viable? (c) What were the effect of CPPS on the academic performance as well as conceptual understanding of students? In other words, how successful was CPPS as a teaching-learning strategy?

Consecutively, five secondary research questions were formulated:

(1) How can the five elements of CL be structured in the design of CPPS?

(2) How successful was CPPS with regards to the structuring of the five elements of CL?

(3) What were the different role players' perceptions of CPPS?

(4) What was the effect of CPPS on the academic achievement of students?

(5) What was the effect of CPPS on students' understanding of thermodynamic concepts?

1.5 Design and methodology

1.5.1 Population and locality

The study was conducted at two South African universities. They will be referred to as University A and University B. The participants were the students enrolled for the first mechanical engineering thermodynamics module. At University A, students took only one mechanical engineering thermodynamics module. The module was taken by mechanical and chemical engineering students in the first semester of their second academic year of study.

At University B, students took two thermodynamics modules. The first introductory module was used in this study and was taken by all mechanical engineering students in the second semester of their second academic year of study. The goal of the two modules at both universities was the same: to serve as an introduction to the fundamentals of mechanical engineering thermodynamics. The only difference between the two universities with regards to content was that thermodynamic cycles were included in the curriculum at University A and not at University B. At University B, thermodynamic cycles formed part of the second thermodynamics module.

At University A, there were two groups, an Afrikaans-speaking group, and an English-speaking group. The resident lecturers presented the lectures, but I was responsible for preparing the tutorials and supervising the Afrikaans-speaking tutorial group. The English-speaking group was supervised by one of the resident lecturers with the aid of a PhD student with several years' experience as a student assistant. There were three student assistants (postgraduate students) providing assistance to each group. At University B, I presented the lectures, and prepared and presented the tutorials. I had the help of a single student assistant, typically a senior undergraduate student.

1.5.2 Research paradigm

In this study, a pragmatic approach towards the research was followed. In the pragmatic approach the focus is on applications that work (Creswell, 2014b), and in this study the goal was to develop and successfully implement CPPS. Also, the pragmatic approach enables the researcher to use multiple methods (Creswell, 2014b). The first subquestion was answered by drawing from the body of scholarship on CL. Empirical data was collected to answer the last four subquestions.

1.5.3 Design of the empirical investigation

A design that is compatible with the pragmatic approach is a mixed methods design which contains both quantitative and qualitative methods (Creswell, 2014b). The mixed methods design has several advantages: It is possible to answer research questions with a wider and broader scope; by combining methods, it is possible to compensate for the weaknesses and utilize the strong points of qualitative and quantitative methods; quantitative data can add precision to qualitative understanding, and finally, stronger evidence can be provided where convergence between the methods exists (Johnson & Onwuegbuzie, 2004).

1.5.4 Method and approach

In order to determine the role players' experiences and perceptions of CPPS (subquestion 2 and 3), qualitative and quantitative data were gathered using a convergent parallel mixed methods design (Creswell, 2014b). The study population was the students enrolled for the respective Thermodynamic courses in 2013 as well as the 2013 student assistants.

Interviews were conducted with individual students, student assistants were asked to fill a questionnaire with six open-ended questions; two observers were asked to attend a tutorial and write reports; the researcher kept a journal, and the students were asked to complete a Likert-scale questionnaire with seventeen questions before and after their exposure to CPPS.

The goal of the questionnaire filled in before exposure to CPPS was to provide a baseline against which to compare the answers in the questionnaire filled in after exposure to CPPS. The questionnaire filled in after exposure to CPPS contained one extra question where students could indicate whether they would have liked to have CPPS implemented again during tutorials in subsequent semesters. Two open-ended questions were also included at the end of the questionnaire as part of the qualitative measurements to determine students' perceptions of CPPS.

To determine whether CPPS influenced academic performance and conceptual understanding (research subquestion 4 and 5), a quasi-experiment was performed comparing the academic performance and conceptual understanding of 2012-groups who were not exposed to CPPS, with the academic performance and conceptual understanding of the 2013-groups, where CPPS was implemented during tutorials. Also, since CPPS was implemented in Thermodynamics every year since 2013 at University B, data on the academic performance of the students of 2014, 2015 and 2016 were also available. This data was used in a correlational analysis to determine the effect that the number of CPPS tutorials students attended had on their academic performance.

An outline of the empirical investigation is shown in Figure 1.1.

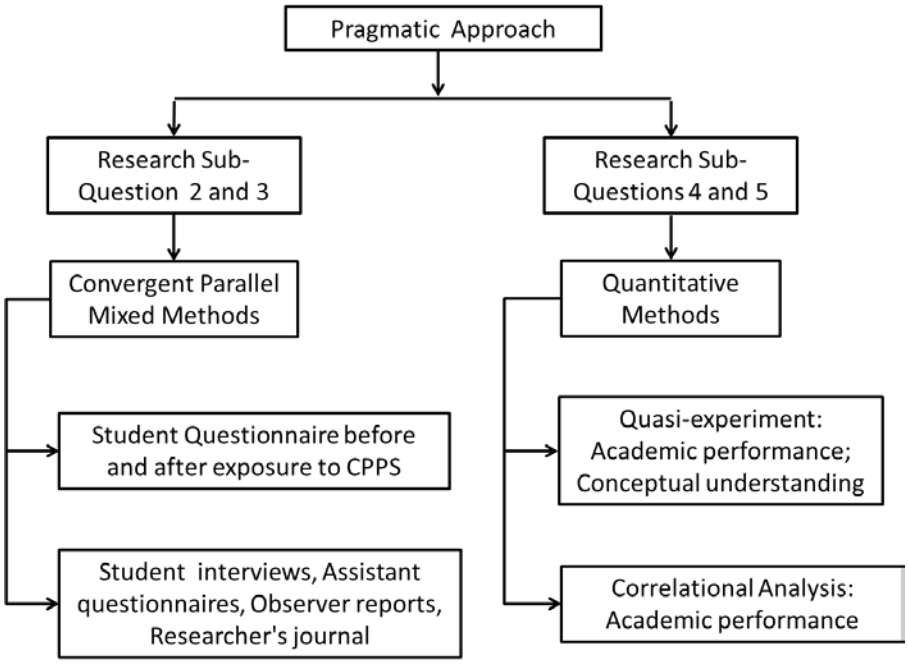

Figure 1.1: Outline of the empirical investigation

1.5.5 Scheduling

The scheduling of the research required to answer the relevant research questions for University A, as well as for University B are shown in Figure 1.2 and Figure 1.3 respectively. In the case of conceptual understanding the goal was to assess understanding and not short-term memory. Therefore, it was decided to test conceptual understanding several weeks after the final examinations when students had their holiday break.

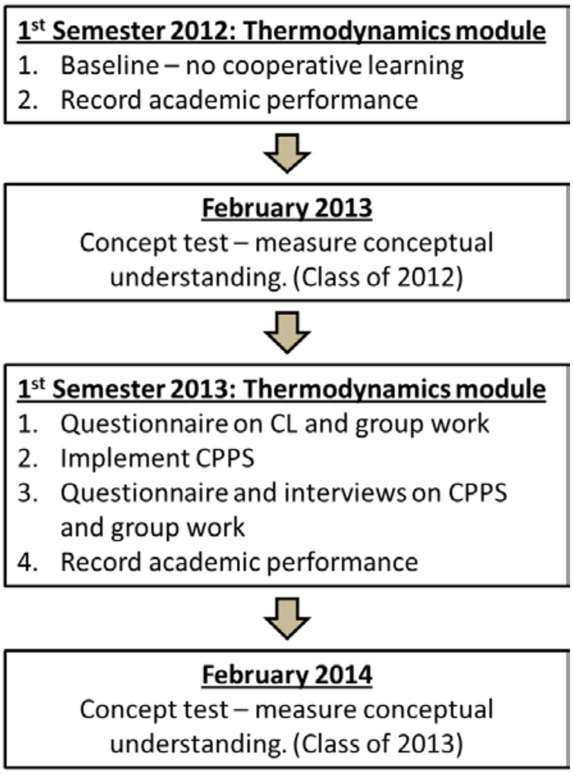

Figure 1.2: Scheduling at University A

The scheduling of the process followed at University B is shown in Figure 1.3.

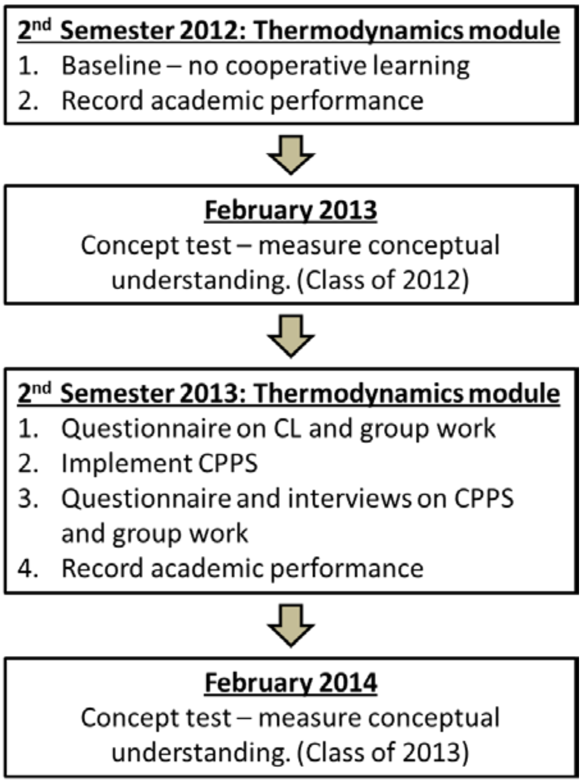

Figure 1.3: Scheduling at University B

1.5.6 Researcher's role

I was given the opportunity to implement CPPS at University A in 2013. I was responsible for the planning of, as well as the necessary preparation for the tutorials. I also supervised the Afrikaans tutorial group. I have been the Thermodynamics lecturer for more than ten years at University B and prepared and supervised the tutorials.

1.5.7 Ethical aspects

Ethical clearance for this work was obtained at University B. The approval letter appears in Appendix A. I had a meeting with the management and lecturers responsible for presenting the thermodynamics module at University A and made a presentation explaining to them the rationale behind the CPPS procedure and the goal and methodology of my research. Subsequently, University A contracted me to coordinate, prepare, and present the tutorials during the first semester of 2013 and the research was conducted with the full support of the departmental management of University B.

An informed consent form was part of the questionnaires students had to complete before and after exposure to CPPS. In the email invitation to interviewees and students' assistants, they were made aware of the goal of the research and that their participation is voluntary and confidential.

1.6 Chapter division

The structure of the thesis is as follows:

(a) Chapter 1: Introduction

Here the background and problem statement of the study are described. The research question and the subquestions are stated. A short description of the method and scope are given.

(b) Chapter 2: Thermodynamics from a teaching-learning perspective

The nature of pure and engineering sciences is explored. The structure of thermodynamics and thermodynamic problems are described. Problem solving, thermodynamic concepts and their comprehension as well as the relationship between conceptual understanding and problem solving are investigated.

(c) Chapter 3: Problem solving in groups: A theoretical perspective

The three theories forming the theoretical framework for CPPS are discussed, followed by a discussion of the elements of cooperative learning making up the model of cooperative learning developed by David and Roger Johnson. The two strategies for problem solving in groups (pair problem solving and pair programming) that forms the basis for the development of CPPS, are investigated.

(d) Chapter 4: Research design, methodology, and execution

In this chapter, the methodology for gathering of the empirical data is described.

(e) Chapter 5: Results and discussion

The results of each of the qualitative and quantitative measurements are discussed.

(f) Chapter 6: Conclusions and recommendations

Drawing from the previous chapters and empirical results, the research questions are answered. I also reflect on the study and propose topics for further study resultant from this study.

1.7 Contribution of the study

A well-structured, easy-to-implement cooperative teaching-learning strategy (CPPS) suitable for large groups of a hundred students or more in engineering science problem-solving tutorials was developed. Due to its sound theoretical basis, CPPS will most probably also be suitable for problem-solving tutorials in other engineering science courses (or even pure science tutorials) and at other universities in these disciplines following a similar approach of lectures and problem-solving tutorials.

The five elements of CL were structured in the procedure. With regards to teaching and learning, CPPS creates an effective teaching-learning environment that: (a) dramatically reduces the teaching load of the instructor (especially in large classes) and creates an effective teaching-learning environment due to active learning and peer instruction; (b) results in a more positive and cheerful atmosphere in class, and (c) improves students' academic performance. These advantages make the implementation of CPPS well worth the effort. Technology was used in innovative ways to reduce the effort of implementation. A laptop and card reader was used to randomly assign students to groups, relieving the facilitator of the responsibility to ensure that groups were formed correctly. Students used their cell phones to submit their answers on a website reducing the effort of grading many answers.

In the next chapter the origin, the nature, and characteristics of engineering sciences in general and thermodynamics specifically, will be investigated.

CHAPTER 2
THERMODYNAMICS FROM A TEACHING-LEARNING PERSPECTIVE

2.1 Introduction

In this chapter, similarities and differences between the natural sciences and the engineering sciences are described. Thereafter the nature and character of mechanical engineering thermodynamics as an engineering science are discussed to identify its specific attributes and the consequences these attributes have for teaching and learning. The two primary goals of teaching an introductory thermodynamics course, namely problem solving and conceptual understanding, are then discussed.

2.2 Thermodynamics: An engineering science

The engineering sciences emerged in the 18th and 19th century when scientists, interested in the application of science, discovered that the recently discovered laws of the natural sciences could not be used as such in engineering. Engineers also realized that their rule-of-thumb and trial-and-error approaches were insufficient to describe engineering artifacts (Channel, 2009).

The growth of engineering sciences resulted from the application of the laws of the natural sciences and mathematics during the study of man-made objects as shown in Figure 2.1.

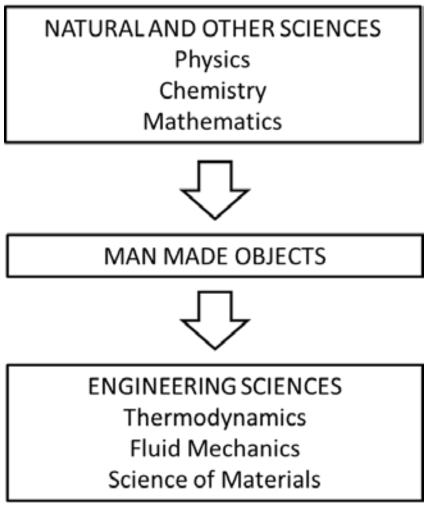

Figure 2.1: The emergence of the engineering sciences

The definition and relationship between natural science, engineering science and engineering are complex, intricate, and ever-changing. It is discussed in great depth in a voluminous book edited by Meijers (2009). The goal of the discussion that follows is an attempt to use insights from the book by Meijers (amongst others) to illuminate the essence and nature of the engineering sciences; thus providing some clarity about the similarities and differences between engineering sciences and natural sciences.

The characteristics of science are discussed first.

2.2.1 Science

Since ancient times humans tried to understand nature by studying and describing various natural phenomena. Due to the contemplative nature of these efforts, trying to make sense of and answering questions about the nature of the physical world, it was originally known as natural philosophy (Channel, 2009, p. 117)[1]. Only in the second half of the 19th century this quest for understanding became known as science where deliberate and active experimentation plays a pivotal role (Okasha, 2002).

Science may be defined in different ways (Mitcham & Schatzberg, 2009) – not all of them helpful in this context. One approach may be to investigate the (often Latin) origin of the word. Another may be to formulate an definition that aims to draw a clear boundary between science and nonscience (Ouweneel, 1992, p. 6).

Dictionaries usually reflect the usage of the word – in what is called the linguistic approach. In the discussion that follows, a pragmatic approach (searching for definitions that work well in a specific context) is used. Using this approach, science can be described as an attempt to describe, understand and explain the object of its study (Okasha, 2002; Radder, 2009). Ziman (1994) adds that the purpose of science is to obtain scientific knowledge. Scientific knowledge is gathered in a systematic way; it is objective, analytical and abstract (Ouweneel, 1992).

2.2.1.1 The natural sciences

During the 16th, 17th, and 18th century, triggered by the Renaissance and the Reformation, the scientific revolution took place in Europe characterized by rapid scientific progress (Okasha, 2002). As the name implies, the natural sciences involve the study of natural phenomena. The structure of the natural sciences is shown in Figure 2.2. It will be shown later that physics as well as chemistry, which are part of the physical sciences, are two cornerstones on which the engineering sciences were built.

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[1] Newton proposed his three laws of motion in 1687 in a three-volume book called *Mathematical Principles of Natural Philosophy*.

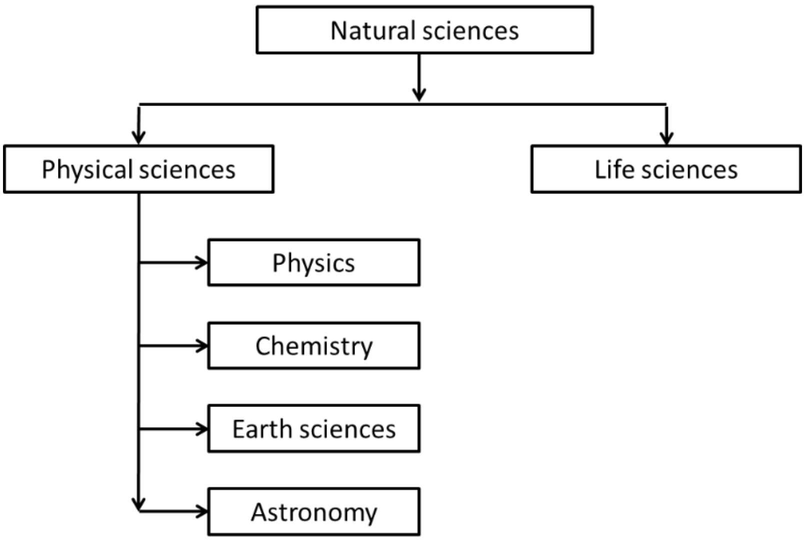

Figure 2.2: The natural sciences

Thermodynamics are studied in both Physics and Chemistry.

Modern physics is defined as the science of matter, motion, and energy. Six main areas of study are distinguished: classical mechanics; quantum mechanics; relativity; optics and electromagnetism; heat and thermodynamics. The latter are described as the statistical description of systems with a large number of particles (Serway & Jewett, 2004).

Chemistry is defined by Silberberg (2009) as "The study of matter and its properties, the changes that matter undergoes and the energy associated with those changes" (p. 4). Chemists also study thermodynamics, but include chemical reactions and reaction equilibrium.

2.2.1.2 Mathematical sciences

Mathematics plays an essential role in natural science and engineering. Solving quantitative engineering, physics and chemistry problems invariably means stating the problem in mathematical terms and then solving the mathematical problem to obtain an answer (Mustoe, 2002).[2] *The Oxford English Dictionary* (2014) describes mathematics as "… the science of space, number, quantity, and arrangement … and which includes geometry, arithmetic, algebra, and analysis; mathematical operations or calculations." The relevance of mathematical skill in engineering sciences is obvious but can easily lead to reducing mathematics to a "bag of tools" that can be used to solve different problems. The focus is then reduced to only teaching students the appropriate procedure to solve a specific problem.

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[2] Our confidence in this approach may be based on the metaphysical belief that nature has a simple mathematical structure (Meijers, 2009, p. 1051).

However, students can benefit in other ways from the study of mathematics. Taylor (1963) argues that for a student, learning the discipline of logical mathematical thought and the associated processes, is just as important as the quantitative aspects of mathematics. Also, much has been made of procedural and conceptual knowledge in the mathematical sciences (Hiebert & Lefevre, 2013). Conceptual knowledge is characterized by the recognition of core features and relationships between pieces of information. Proper conceptual knowledge leads to deep understanding which enables students to generalize and apply knowledge and procedures in other contexts – such as engineering (Molefe, 2006).

2.2.2 Engineering

The word *engineer* emerged in the late Middle Ages, referring to someone who built "engines of war". Architects were responsible for the planning of civil constructions and were also responsible for the technical aspects such as hydraulics and mechanics. In the 18th century, as the Industrial Revolution began a "military-like exploitation of nature" (Mitcham & Schatzberg, 2009, p. 41), the word *civil engineer* was coined. However, in 1828 the British Institution of Civil Engineers still defined engineering as an art: "Engineering is the art of directing the great sources of power in nature for the use and convenience of man" (quoted by Mitcham and Schatzberg (2009, p. 41)).

It was perhaps inevitable that scientists would study the technological artifacts associated with the industrial revolution to understand and improve their functioning. This scientific approach changed the nature of engineering from a craft (or art) to a science (Layton, 1971) and thus engineering science was born. This transformation is reflected in the definition of engineering in the Merriam-Webster dictionary (*Merriam-Webster dictionary*, 2014): "The application of science and mathematics by which properties of matter and the sources of energy are made useful to people." Engineers became scientists in their own right (Hansson, 2007).

Although it may be possible to give typical examples of a pure and engineering sciences (and technology), it is much more difficult (if not impossible) to divide them neatly into watertight compartments. They overlap and exist in a symbiotic relationship and are perhaps best seen as interdependent (Channel, 2009). However, engineering sciences share the quest for understanding and the accumulation of scientific knowledge as a family characteristic with the pure and applied sciences.

2.2.3 Engineering sciences

Engineering sciences have a unique aim. Whereas the natural scientist strives for better understanding (in other words more scientific knowledge) – or according to Houkes (2009, p.

312) “the truth” – the engineer evaluates scientific knowledge on the basis of its usefulness in the design process (Hansson, 2007). Design is a defining activity of engineering – it is the conceptualization and quantification of the characteristics of an artifact (human-made object) that must meet a predetermined set of requirements. During the design process, the engineer must take technical, economic, health and safety, legal, social and environmental constraints into account and incorporate them all in the design (Engineering Council of South Africa [ECSA], 2012).

To be useful, engineering scientists may have to develop their own theoretical and empirical knowledge. A prime example is the electrical industry that was built up by inventors (such as Edison) for commercial gain that would not have been possible without the theoretical understanding established by natural scientists such as Faraday. Another, more recent example is nuclear technology for power generation built directly on the research by physical scientists (Ziman, 1994).

Another characteristic of engineering sciences is that they focus on human-made objects rather than the natural world (Hansson, 2007). Whereas physicists may normally study a fixed, quiescent amount of matter, engineers typically study systems through which matter flows, and how these systems interact with the environment (Moran & Shapiro, 1995).

For example, an engineer may use thermodynamics to design, simulate and optimize power conversion processes, but an atmospheric scientist may use thermodynamics to study atmospheric processes (Zdunkowski & Bott, 2004).

As natural science aims to explain the underlying principles of the natural world, far-reaching idealisations are often made to isolate natural phenomena from each other – resulting in “ideal” processes. Because technological objects need to function in the real world, idealizations that are useful in the natural sciences can often not be made in engineering sciences (Hansson, 2007).

Natural scientists also search for analytical solutions to problems as such solutions may reveal the underlying relationship between different variables. Engineering sciences are often satisfied with solutions that are sufficiently accurate for the intended purpose and often obtain these solutions from numerical procedures (Hansson, 2007). In Engineering, several factors that impact on performance are often lumped together in a single variable and empirical relationships between different variables are common. To account for possible uncertainties in specification and design, safety factors are used (Hansson, 2009).

2.2.3.1 Mechanical Engineering Thermodynamics

Measured against the characteristics of engineering sciences discussed in the previous paragraph, mechanical engineering thermodynamics is in many ways a typical example of an engineering science. The development of mechanical engineering thermodynamics as an engineering science was driven by the need to improve the efficiency of the steam engines developed by Newcomen and Watt (as cited by Channel, 2009). Thermodynamics uses the understanding developed in physics and chemistry to study energy and its conversion – in the case of the steam engine, the conversion of heat into work or in internal combustion engines, the conversion of the energy in liquid fuels into motive power (Borgnakke, 2014). The understanding developed in physics into the behavior of many particles was used as a basis to develop terminology and calculation procedures that can be used in the design of *open systems* – devices where flow into and out of the system takes place such as turbines and compressors. The understanding developed in chemistry into combustion processes was used to understand and optimize the combustion of large quantities of coal and other fossil fuels in power stations. As power conversion systems can be large and complex, it was necessary to develop new knowledge necessary for the design and simulation of the components and the integrated systems. Mechanical engineering thermodynamics is described as the study of energy and energy conversion and the substances involved in the conversion process.

2.3 The nature and structure of thermodynamics

Thermodynamics can be structured according to a few important key concepts and this structure is simple and elegant (Gilmore, 2008). The concepts, their nature, organisation, and impact on understanding thermodynamics will now be discussed. To make the discussion easier to follow, thermodynamics concepts will be used as examples.

2.3.1 Concepts in Thermodynamics

Hiebert and Lefevre (2013) describe concepts as pieces of information in a rich network of relationships. A concept therefore consists of two aspects, namely the *piece of information* and the *network of relationships*. Consider the thermodynamic concept of internal energy. It is defined as the sum total of all the microscopic forms of energy of the molecules comprising a substance (Cengel & Boles, 2007). One of the forms of microscopic energy is the kinetic energy of the individual molecules of the substance[3] due to their linear velocity. The linear velocity of a

[3] Substances consist of atoms or molecules. In this discussion molecules or particles will be used to refer to both.

water molecule in steam will be higher than the linear velocity of a water molecule in ice as shown in Figure 2.3.

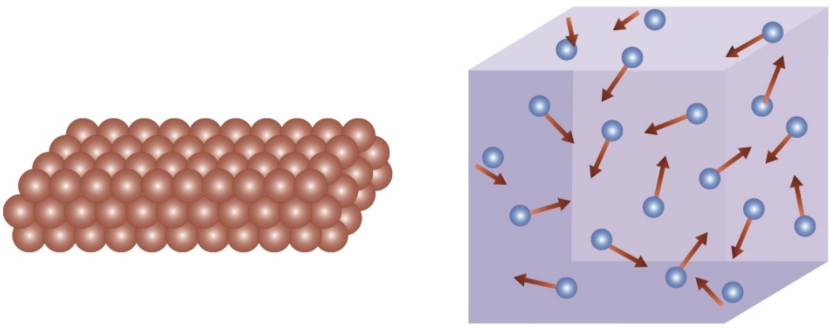

Figure 2.3: Water molecules in ice and in steam

There are also other forms of microscopic energy. Molecules can also rotate or vibrate. The sum of all these forms of energy is the internal energy of a substance. This description of internal energy is the first part of the concept, the piece of information. The second aspect is the network of relationships between the pieces of information. Internal energy and heat are related. When heat is added to liquid water, its temperature will rise and the liquid water will eventually start to boil and turn into steam. The energy added as heat is absorbed by the liquid water molecules and the average linear velocity of the molecules increases dramatically as the liquid water turns into steam.

Relationships therefore exist between internal energy, heat and temperature and are often expressed in mathematical form. This network of relationships is the second aspect necessary to complete the concept of internal energy. Knowing the definition of internal energy is therefore different from a conceptual understanding of internal energy. Conceptual understanding implies knowing what internal energy is, its definition, and how it is related to other concepts – in this case heat and temperature.

Steam flowing in a pipe can be used to turn a turbine and perform work such as turning a generator or pulling a train. Due to velocity at which the steam flows, the steam (on a macroscopic level) also possesses kinetic energy. All these forms of energy (internal energy, macroscopic kinetic energy, heat, and work) are accounted for in the first law of thermodynamics. The first law states that energy cannot be created or destroyed and to be consistent with the terminology used thus far, the formulation of the first law must be seen as a piece of information related to the forms of energy included in its formulation. The first law plays a crucial role in providing structure to the concepts in thermodynamics.

2.3.1.1 The nature of thermodynamic concepts

When discussing reasons why students find Thermodynamics difficult, several authors mention that Thermodynamics and its related concepts are abstract (Baker, Ezekoye, Schmidt, Jones, & Liu, 2000; Blicblau & Van der Walt, 2008; Ceylan, 2012; Foley, 2007). *The Oxford English Dictionary (2014)* defines *abstract* as: "Existing in thought or as an idea but not having a physical or concrete existence." Castellanos and Enzer (2013) and Keith, Silverstein, and Visco (2008) mention that Thermodynamics lacks an intuitive feel. Although thermodynamic devices such as refrigerators and internal combustion engines surround us, we normally cannot use our senses to perceive and experience the thermodynamic processes taking place inside these devices. In contrast, it is easy to make a visual presentation of the components of the structure (Baker et al., 2000) in a discipline such as structural analysis and students should have an intuitive feel for compression and tensile forces.

According to Carl Jung, people tend to perceive the world through sensing and intuition (Felder & Silverman, 1988). Sensors prefer facts and concrete data while intuitors prefer principles and theories and will look for hidden patterns. Intuitors will probably be more comfortable with the abstract and conceptual nature of thermodynamics with its rich network of relations and abstract concepts. According to Felder and Silverman (1988) researchers have come to the conclusion that the majority of engineering students are sensors. This might be an important reason that students struggle with thermodynamics.

2.3.1.2 The structure of thermodynamic concepts

In Figure 2.4, a graphical presentation of the structure of thermodynamics according to Turns and Van Meter (2011) is shown.

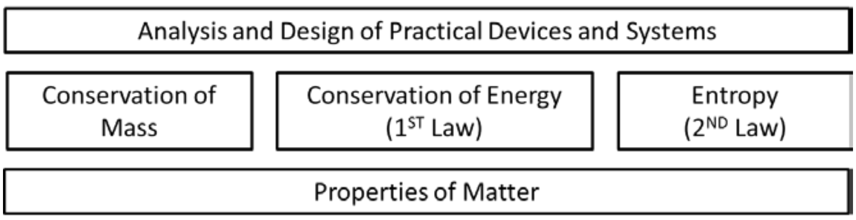

Figure 2.4: The structure of thermodynamics

Figure 2.4 shows a hierarchical structure. The basis for this structure is properties. Substances (such as air and steam) have quantitative properties (such as pressure and temperature) that are used to define their state and calculate other properties such as density and internal energy. The next layer in this structure contains three key concepts. The first concept and second concept are closely related, namely the conservation of mass and energy that state that mass and energy cannot be created or destroyed and is therefore conserved. The conservation of mass and energy are often also called principles (Turns & Van Meter, 2011). The third element in the middle layer is entropy.

From a molecular point of view entropy can be described as an indication of molecular disorder (Cengel, Boles, & Kanoglu, 2011). The molecules of a perfect crystal are completely ordered and stationary at a temperature of absolute zero. Therefore, the entropy of such a crystal is zero. As heat is added and the crystal heats up and eventually starts to melt and later vaporize, the molecules will begin to move and become increasingly disorganized – as shown in Figure 2.3. As heat is added to the substance the molecular disorder and therefore the entropy increases. In reversible (ideal) processes where there is (amongst others) no friction or temperature gradients, the total entropy of the system consisting of the melting crystal and the heat source stays constant[4], but in irreversible (real) processes where there are friction and temperature gradients, the total entropy of the system increases (Cengel & Boles, 2007). In Figure 2.4, the first two layers form the framework that facilitates the eventual goal of thermodynamics from an engineering perspective: the analysis and design of practical devices and systems.

The information part of concepts (such as internal energy and entropy) is unambiguously and rigorously defined, but the network of relationships between the pieces of information can be arranged and constructed in different ways. The concept of entropy provides such an example.

The second law and entropy has been identified as one of the important though poorly understood concepts in Thermodynamics (Midkiff, Litzinger, & Evans, 2001; Miller, Streveler, Yang, & Roman, 2011). Cengel and Boles (2007) follows the same sequence as Borgnakke (2014) and explain entropy starting from the second law and then apply entropy in the solution of problems of reversible and irreversible processes. This approach uses a difficult-to-understand concept – the second law – as the departure point to describe another difficult-to-understand concept, namely entropy. Using a difficult to understand concept (the second law) to explain entropy may make it even more difficult to properly understand the concept of entropy.

Other possibilities do exist to construct relationships involving entropy and the second law. One possibility is to explain entropy, not using the second law, but in a similar fashion as internal energy, as in the previous paragraph, from a molecular viewpoint (Keith et al., 2008). Entropy can then be applied in first solving reversible and then irreversible system problems. This approach offers an alternative explanation of the second law that some students may find easier to understand. This alternative approach is shown in Figure 2.5.

[4] As the heat source loses heat, its entropy will decrease while the entropy of the melting crystal will increase.

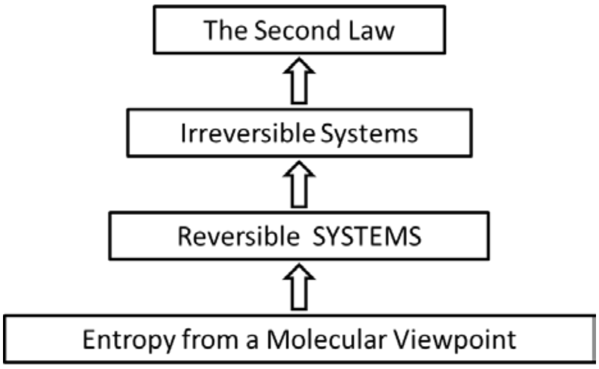

Figure 2.5: An alternative sequence for explaining entropy and the second law

The concept map of thermodynamics contains many concepts with intricate relationships between them. Just as in the case of entropy and the second law, these pieces of information and the relationships between them can be arranged in different ways. Therefore, students of thermodynamics will probably build their own unique concept maps of thermodynamics.

The comprehension of the concepts in thermodynamics build on each other and form a single interrelated complex network (Ceylan, 2012). A student that falls behind will therefore probably struggle to understand the concepts introduced later in the course resulting in an incomplete understanding and a fragmented network of relationships between concepts. In heat transfer, it is different as it is possible, for example, to understand radiation heat transfer without having a proper grasp of conductive heat transfer.

2.4 Thermodynamic problems

Both in engineering and in science, the students' ability to solve problems is a very important outcome of tertiary education. Both the American Accreditation Board for Engineering Teaching (ABET, 2013) and the Engineering Council of South Africa (ECSA, 2014) state that an essential outcome for any engineering program is the ability of students to identify, formulate and solve engineering problems. In the workplace engineers are employed to solve problems (Jonassen, Strobel, & Lee, 2006). Several authors also see the ability to solve problems as an important, if not primary, goal of a science education (Becerra-Labra, Gras-Martí, & Torregrosa, 2011; Docktor et al., 2010; Surif, Ibrahim, & Dalim, 2014; Wallace, 2014). As engineering thermodynamics is an engineering science, there will be significant agreement between the characteristics of problems in physics, chemistry, and thermodynamics taught in the physical sciences.

2.4.1 Classification of problems

Turns and Van Meter (2011) categorize thermodynamics problems with regards to two considerations: the type of process and the type of system. These concepts will now be explained.

When we add heat to a system and its temperature rises, we say its state has changed. In thermodynamics, the word *process* is used to describe the change a system undergoes as it goes from one state to the other. The heating of water is therefore a state-change process. The time duration of a state-change process is not relevant and is therefore not specified. In a time-dependent process, the time duration of the state change is specified. An example of a time-dependent process is when an amount of water is heated from temperature A to temperature B in a specified time. The third type of process is a steady-state process. Consider a jet engine in the middle of a long-distance flight. The temperature and pressure of the inlet air and outlet gases as well as other conditions in the jet engine remain constant for a long time. Such processes where conditions remain the same for long times, are called steady-state processes.

The second consideration is whether a system is open or closed as shown in Figure 2.6. A closed system consists of a fixed amount of matter like water in a pot. In thermodynamics, the .most common closed system is a fixed amount of a substance (such as air or steam) contained inside a piston cylinder arrangement. In an open system, mass flows in and out of the system. A typical open system is the jet engine mentioned above or a heat exchanger such as a radiator of a car where the hot cooling water of the car is cooled in the radiator by cool atmospheric air.

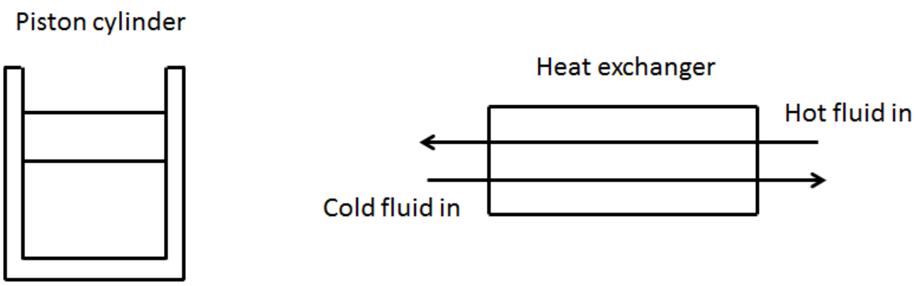

Figure 2.6: A piston cylinder (closed) and heat exchanger (open system)

In total, six combinations are possible between the two types of systems and the three types of processes. These six combinations (adapted from Turns and Van Meter (2011)) are shown in Table 2.1.

Table 2.1: Problem categories in Thermodynamics

Type of Process	Type of System	
	Closed	Open
Time dependent	1	2
State change	3	4
Steady state	5	6

Although it is possible to formulate problems of type 1 and 2, generally students in introductory thermodynamics are only required to do problems in category 3, 4, 5 and 6 (Turns & Van Meter, 2011).

To solve a problem, it is only necessary to identify the type of problem from Table 2.1 and apply the relevant equations and formulas. However, this is not as simple as it sounds as there are three different types of substance (real substances, ideal gases, and perfect gases) and there are several process paths possible between the initial and final states (constant pressure and constant temperature – to name two) and a variety of systems (such as turbines, compressors, and heat exchangers – to name thrFee). The result is that many different problems can be formulated. Borgnakke and Sonntag (2009) contain more than 2000 end-of-chapter problems and Cengel and Boles (2007) included 700 new problems in that edition.

2.4.2 Level of complexity of problems

Normally only simple arithmetic is required to solve thermodynamics problems (Ceylan, 2012). Whereas physicists may use statistics to describe the large number of particles in a thermodynamic system, engineering thermodynamics describe the behavior of substances from a macroscopic point of view (Borgnakke, 2014). A single value can therefore be used for the properties of a component such as the temperature of the air or the entropy of steam. Usually the detailed field distribution of these properties – for instance the velocity profile of a fluid flowing in a pipe – is not considered and it is not necessary to engage in advanced mathematics such as vector calculus and partial differential equations (Probst & Zhang, 2013).

2.4.3 Structuredness of problems

According to Jonassen et al. (2006) the type of problems engineers are likely to encounter in the workplace will be ill-structured and complex with conflicting goals, more than one solution strategy and several possibilities of problem representation. He studied hundreds of problems and split them into eleven problem types ranging from well-structured to ill-structured as shown in Table 2.2.

Table 2.2: Well-structured and ill-structured problems (Jonassen et al., 2006)

Structure	Problem type
Well-structured	Logical
	Algorithmic
	Story
	Rule-using
	Decision-making
	Trouble-shooting
	Diagnostic solution
	Strategic performance
	Case analysis
	Design
Ill-structured	Dilemmas

Johnstone (1993) and Wood (2006) classified problems according to (a) amount and nature of the information supplied, (b) clarity of the goal and (c) solution method to be followed. Different combinations between these three variables result in eight problem types ranging from problems where (a) all the data are available, (b) familiar methods can be used and (c) the goal is clear (algorithmic problems), to problems with missing data, unfamiliar solution methods and poorly defined goals. This classification of problems results in a similar spectrum as in Table 2.2 with problems ranging from well-structured to ill-structured.

Woods (2000) distinguishes between exercises, problems, and complex problems. For exercises, the connection between the given information and the goal is obvious and it is possible to start from the given information and reach the goal or solution. Other terms used for exercises include *algorithmic*, *typical,* or *reproductive problems*. In the case of the second category, problems, no obvious or immediate connection can be made between the given information and the goal. It is necessary to devise some sort of plan or strategy. It may for instance be necessary to also work backwards from the solution to find a solution path between the given information and the goal. Words such as *ill-defined* are used to describe this type of problems. Complex problem situations consist of several sub-problems that must be solved.

In a study involving second-year chemistry students, Surif et al. (2014), distinguished between algorithmic, conceptual, and open-ended problems. *Open-ended* problems are ill-defined and do not have single unique answers. It requires students to use their conceptual understanding. The term open-ended does not appear in the list in Table 2.2, but can perhaps best be considered as ill-structured.

The second type of problems mentioned by Surif et al. (2014) is conceptual problems. Conceptual problems also contain all the required data and a clear goal, but instead of manipulating numbers and solving equations, these problems are qualitative, therefore students need to rely on their conceptual understanding to obtain an answer. Conceptual problems can perhaps best be seen as similar to logical problems listed in Table 2.2. Both Cengel and Boles (2007) and Borgnakke (2014) include concept questions as part of the end-of-chapter problems to facilitate the evaluation of students' conceptual understanding.

Most problems in the introductory engineering science courses are logical, algorithmic, or well-structured story or word problems (Jonassen et al., 2006; Wood, 2006). In more advanced courses and as practicing engineers, students will encounter problems that are more ill-structured.

2.5 Conceptual understanding and problem solving

Apart from developing problem-solving skills, conceptual understanding is also part of the knowledge pursued by scientists and an important goal of tertiary education (Gok, 2014; Gultepe, Yalcin, & Kilic, 2013).

The relationship and possible interactions between the conceptual understanding and problem solving will now be considered, as well as the assessment of conceptual understanding and problem solutions strategies.

2.5.1 The interaction between conceptual understanding and problem solving

Ridenour, Feldman, Teodorescu, Medsker, and Benmouna (2013), wanted to improve their students' problem-solving skills by teaching them a problem-solving protocol. In an introductory algebra-based physics course, they introduced ACCESS (Assess the problem, Create a drawing, Conceptualize the strategy, Execute the solution, Scrutinize your results, Sum up your learning). They do not consider the possibility of interaction between conceptual understanding and problem-solving skills and conclude that it is possible to overemphasize one at the expense of the other.

Apparently, most researchers do not see problem solving and conceptual understanding in isolation. Some see conceptual understanding improving as a result of problem solving. Both Gultepe et al. (2013) and Gaigher, Rogan, and Braun (2007) stated that chemistry teachers and physics instructors generally believe that problem solving by students will result in conceptual understanding and that the ability to solve problems is equivalent to understanding (molecular and mathematical) concepts (Nakhleh & Mitchell, 1993; Nurrenbern & Pickering, 1987).

However, several authors agree that the ability to apply algorithms and solve mathematical problems does not indicate conceptual understanding (Gok, 2014; Gultepe et al., 2013; Nakhleh & Mitchell, 1993; Salta & Tzougraki, 2011; Surif et al., 2014). When the emphasis is on problem solving, it seems students are better rewarded by rote learning than by conceptual understanding (Brooks & Koretsky, 2010; Case & Marshall, 2004; Jonassen et al., 2006). Students often see problem solving as an "exercise in manipulating equations, symbols and quantities with the goal of obtaining the correct answer" (Docktor et al., 2010, p. 137) and are often able to solve problems (using the appropriate strategy) without understanding the concepts (Gultepe et al., 2013).

Others try to integrate conceptual understanding with problem solving. According to Kuo, Hull, Gupta, and Elby (2013) science education literature proposes that conceptual reasoning be introduced during two stages of problem solving: the initial qualitative analysis of the problem in order to determine the relevant equation to be used and secondly during the interpretation of the answer in order to determine whether it makes sense. They argues that problem-solving skills includes the ability to opportunistically blend conceptual understanding and formal mathematical reasoning throughout the problem-solving process and that teaching opportunistic blending is a feasible instructional target.

Leonard, Gerace, Dufresne, and Mestre (1999) state that problem solving is about making decisions and that conceptual understanding will lead to better decisions and therefore also better problem solving. Already in the early nineties, Heller, Keith, and Anderson (1992) recognized that students need to be able to apply their conceptual understanding when solving problems. According to her some students see the two as separate. They either understand the material, but cannot solve the problems, or they can solve worked problems but lack the conceptual understanding to apply this skill in an unfamiliar context. And finally, some authors see conceptual understanding as a pre-requisite for solving ill-structured problems (Jonassen et al., 2006).

It is evident that the type of problem influences the role played by conceptual understanding during problem solving. For well-structured problems, rote learning can compensate for a lack in conceptual understanding. For ill-structured problems, conceptual understanding is an integral part, a prerequisite of a successful problem-solving process. As problems lie on a spectrum between well-structured and ill-structured, the importance of conceptual understanding in the problem-solving process will increase as well-structured problems become more ill-structured.

Except in design courses and capstone projects, undergraduate students are generally required to solve reasonably well-defined problems (Jonassen et al., 2006). This is also the case for introductory thermodynamics. Although it may be possible to solve well-structured problems with limited conceptual understanding, conceptual understanding is necessary to solve design problems in the more senior years and conceptual understanding is as important as problem-solving skills. Both Cengel and Boles (2007) and Borgnakke (2014) include a few concept problems with the end-of-chapter problems.

It is therefore possible that confronting students with challenging problems may force them to make some effort to better understand concepts.

2.5.2 Evaluating conceptual understanding

As it became clear that all problem solving does not necessarily promote conceptual understanding and that students could solve algorithmic problems even with poor conceptual understanding, more attention should be given to conceptual understanding and its assessment. Several approaches for evaluating students' conceptual understanding exist.

In their teaching of chemistry, Nurrenbern and Pickering (1987) introduced pairs of conceptual and algorithmic questions testing the same principle. The traditional algorithmic questions were quantitative in nature while the concepts questions were qualitative in nature and students had to rely on their conceptual understanding to obtain an answer. They stated that the approach of paired problems has important limitations. It is possible that the emphasis placed during teaching on quantitative problem solving is the reason students' in their study were better able to solve the quantitative problems and that, if the same effort was made to teach conceptual understanding, the score in the conceptual tests would also improve – as was found by Ridenour et al. (2013).

Conceptual and algorithmic pairs were also used by Cracolice, Deming, and Ehlert (2008) and according to Salta and Tzougraki (2011) such pairs are commonly used in chemistry. In physics Singh (2008) developed problems called Conceptual and Quantitative Isomorphic Problem Pairs (CQIPP). The problems are called isomorphic because the same physics principle is necessary to solve them. He found that exposing students first to the quantitative problems helped them to make conceptual inferences using quantitative tools. In a future study, he was planning to expose students to the conceptual questions first to determine whether students' problem solving ability benefits from first thinking conceptually. Coştu (2007) used the number of steps in a problem to distinguish between pupils who used an algorithmic approach from those who could apply their conceptual understanding. Pupils who could solve problems requiring four or more steps were considered conceptual problem solvers while those who could only solve problems which required one, two or three steps as algorithmic problem solvers.

An approach which seems common is the tiered multiple-choice question (Salta & Tzougraki, 2011; Surif et al., 2014). Students are presented with a scenario and must choose an answer. In the subsequent question they must choose the reason they selected the specific answer of the previous question. Typically, all the options in the second question are true but not all are relevant.

Two years before Nurrenbern and Pickering (1987) studied students' conceptual understanding in chemistry, Halloun and Hestenes (1985) introduced the Force Concept Inventory in physics to test students' understanding of Newtonian force concepts. Since then many concept inventory tests for different disciplines were developed (Wattanakasiwich, Taleab, Sharma, & Johnston, 2013).

In thermodynamics several tests were also developed (Midkiff et al., 2001; Prince, Vigeant, & Nottis, 2013; Streveler et al., 2011; Wattanakasiwich et al., 2013). Miller et al. (2011) in cooperation with Streveler et al. (2011) asked a number of experts to identify difficult concepts in the heat transfer, thermodynamics and fluid mechanics domains. They identified approximately 60 ideas which were coded and organized into 28 concepts of which 18 are relevant to thermodynamics. From this list, they identified seven concepts which they considered were highly important but poorly understood. They developed a test, the Thermal and Transport Concept Inventory (TTCI) evaluating students' understanding of these concepts. The test is multiple choice and some questions are tiered pairs as discussed before. Another multiple choice concept test, the Thermodynamics Concept Inventory (TCI) was developed by Midkiff et al. (2001). Based on student misconceptions as noted by the authors and their colleagues, they identified six concepts that they included in their test.

Both the TTCI and TCI tests evaluate the understanding of the following concepts:

- The second law
- The conservation of mass
- The conservation of energy, work, and heat (TCI) which resembles the conversion of thermal energy into work (TTCI)
- The properties and behavior of matter (TCI) which includes the ideal gas law (TCCI)

Wattanakasiwich et al. (2013) developed the Thermodynamic Conceptual Survey (TCS) with a narrower scope which only tested conceptual understanding of temperature and heat transfer, the ideal gas law and the first law of thermodynamics. Tongchai, Sharma, Johnston, Arayathanitkul, and Soankwan (2009) also mention other, more time consuming methods to identify student conceptual understanding such as open-ended questions, concept maps and interviews. Kautz and Schmitz (2007) used clickers during the lecture to get quick feedback on students' (mis)conceptions.

It is evident from the literature that there is not an emerging consensus on which concepts to test for and how to test them. No instances could be found where concept tests were used for summative assessment. It seems that concept tests are used as a diagnostic tool – to identify possible shortcomings in teaching, or test improvement in conceptual understanding of students after completing a course (Wattanakasiwich et al., 2013). It seems, just as every student will construct his own network of relationships between concepts, that there is some variation in what different compilers of concept questions consider as important. For instance, the TCCI considers understanding the difference between steady state and equilibrium as one of the important but poorly understood concepts, while neither Cengel and Boles (2007) nor Borgnakke (2014) pays much attention to it.

2.6 Summary

Since ancient times, humans tried to understand nature. During the scientific revolution, the contemplative nature of these efforts changed and much more emphasis was put on active experimentation and solving problems. The engineering sciences emerged as scientists discovered that the recently discovered laws of nature could not be used as such to solve practical problems and engineers and tradesmen discovered the limitations of time-honored, rule-of-thumb and trial-and-error procedures.

Although engineering sciences share as a family characteristic the accumulation of scientific knowledge (as opposed to practical knowledge) with all sciences, it generally evaluates knowledge based on its usefulness in the design process. Engineering scientists often develop their own theoretical and empirical knowledge – focusing on human-made objects rather than the natural world.

The development of thermodynamics as an engineering science was driven by the desire to improve the efficiency of the steam engines developed by Newcomen and Watt. Thermodynamics is described as the study of energy and energy conversion and the substances involved in the conversion processes. A typical example of the conversion of energy is the conversion of heat into mechanical (shaft) power necessary to turn electrical generators or the wheels of a motor car.

Thermodynamics can be structured simply and elegantly around three concepts: the conservation of mass, the conservation energy (the first law), and entropy (the second law). The concepts in thermodynamics are abstract and lack an intuitive feel. This is because thermodynamic processes generally take place inside devices and we cannot use our senses to perceive and experience the processes.

Conceptual understanding implies an understanding of the factual part of the concept, as well as an understanding of the relationships that exists between concepts. The factual parts of thermodynamic concepts are defined unambiguously and rigorously. However, the sequence and manner in which relationships between concepts are introduced and explained to students can be changed to make for easier understanding. Several approaches to assessing conceptual understanding exist, but it is normally not part of summative assessments but rather used as a diagnostic tool.

The ability to solve problems is an important outcome of engineering education. The relationship between the ability to solve problems and conceptual understanding is complex.

Well-defined, algorithmic problems can often be solved with limited conceptual understanding. However, sound conceptual understanding is necessary to solve ill-structured and design problems. In introductory thermodynamics, students generally need to solve reasonably well-structured problems. In design courses, problems are more open-ended and ill-structured. Students need to develop sufficient conceptual understanding in the introductory thermodynamics course to enable them to solve these ill-structured problems in their later years of study and as practicing engineers.

CHAPTER 3
PROBLEM SOLVING IN GROUPS:
A THEORETICAL FRAMEWORK

3.1 Introduction

In Chapter 2 it was shown that thermodynamics can be structured simply and elegantly according to three concepts: the conservation of mass; the conservation of energy and entropy. It was shown how the relations between the concepts in the concept map of thermodynamics can be built up in different ways. It was established that well-structured, algorithmic problems can often be solved with limited conceptual understanding but that for ill-structured problems, a deep conceptual understanding is required. The students in this study had to solve reasonably well-structured problems where it was often still necessary to set up a solution strategy of several steps for which substantial conceptual understanding would have been necessary. Tutorials provided students with the opportunity to develop their problem-solving skills by solving problems with the help of a lecturer or teaching assistant.

In several studies researchers have concluded that working in groups under the right conditions can have many teaching and learning benefits (Johnson & Johnson, 2013). In this chapter a theoretical framework for a cooperative learning procedure, where students solve problems in groups of two, are proposed.

3.2 A theoretical framework

The framework is based on three perspectives that, according to Johnson and Johnson (2013, p. 87), has guided research on cooperation: perspectives on the development of cognition, perspectives on social behavior, and perspectives on social interdependence. A discussion of cooperative learning follows the description of the framework.

3.2.1 Theories of learning

Theories make it possible to formulate hypotheses (Schunk, 2004), but also to explain phenomena and provide guidance for decision making and action (Ormrod, 2009; Siemens, 2006). Learning theories can therefore serve as a rational point of departure for the development of teaching-learning strategies and procedures. There are many theories that describe how learning is supposed to take place. For clarity, the different theories are often grouped together in different ways.

According to Ertmer and Newby (2013), learning theories are typically divided into two categories: behaviourist and cognitivist, but they add a third category, constructivist theories. James (2006) distinguishes between three clusters of learning theories in literature: (i) behaviourist, (ii) cognitivist, and (iii) sociocultural and situated theories. An overview using the latter grouping is now given.

According to behaviourist theories, learning is largely the result of environmental events: "The hallmark of behavioural theories is not that they deal with behavior (all theories do that) but rather that they explain learning in terms of environmental events" (Schunk, 2004, p. 29). From a behaviourist viewpoint, learning has taken place when the appropriate response (behavior) follows a specific stimulus (Ertmer & Newby, 2013). Behaviorists therefore equate learning with a change in behavior. Although not denying the existence of mental phenomena, these theories contend that such phenomena are not necessary to explain learning (Schunk, 2004). The behaviourist approach can be used to develop routine expertise and skills that can be used in contexts similar to those in which they were learned (Bell & Kozlowski, 2008).

Cognitivist approaches consider learning and behavior as two separate phenomena. Learning is seen in the first place as a mental activity (Ormrod, 2009) and there is an emphasis on understanding (James, 2006). In this vein, Ormrod (2009, p. 4) defines learning "as a long-term change in mental representations or associations as a result of experience". Cognitivist scientists will study how the mind processes and retrieves information, the differences between the mental processes of experts and novices and the monitoring and regulation of mental processes (metacognition) (Ertmer & Newby, 2013). Cognitivist theories are more appropriate to explain how people learn to perform more complex tasks (than mere conditioned behavior), such as the processing and retrieval of information, solving complex problems, and complex reasoning (Ertmer & Newby, 2013).

Constructivism can be seen as a branch of cognitivism as both consider learning a mental activity (Ertmer & Newby, 2013). However, according to the constructivist view, knowledge is not something objective; acquired by or mapped onto the mind of the student, but infers that each student creates his or her own understanding from experiences and observations. Knowledge is therefore not independent of the student nor the context (Schunk, 2004).

Active learning is an approach grounded in constructivism (Bell & Kozlowski, 2009). Active learning approaches take the view that "when students are actively engaged in the learning process, they learn better" (Liu, Mauthner, & Schwarz, 2009, p. 106). Though not always the distinguishing characteristic or core element of a strategy or method, some strategies *by their nature*, engage the student in the learning process (Prince, 2004; Prince & Felder, 2006) and can therefore be considered active learning strategies.

The third category in the grouping used by James (2006) is sociocultural and situated theories of learning. According to this grouping, learning takes place in the interaction between the social environment and the individual. The situated approach emphasizes the need of students to immerse themselves in authentic environments while the sociocultural approach emphasizes the fact that students construct meaning through their interaction and cooperation with others – be it peers or members of the same community of people with which they aspire to work with (Grabinger, Aplin, & Ponnappa-Brenner, 2007). According to James (2006), what is learned in situated and sociocultural learning, is often learned by the group and it is not always possible to isolate the individual's contribution or assess his ability in isolation from the group and that more work needs to be done to develop better assessment practices.

Whereas constructivist approaches are well suited to disciplines such as science and mathematics (James, 2006) and more advanced knowledge acquisition and problem solving (Ertmer & Newby, 2013), constructivists have realized the importance of the social dimension of learning, leading to the development of approaches which combine aspects from the different perspectives (Giustini, 2014; James, 2006). An example of such a combined approach was pioneered by Albert Bandura and his co-workers during the late fifties and early sixties. They showed that people can learn new actions by merely observing other people. Initially known as the social learning theory, it assimilated more and more cognitive elements and became known as the social cognitive theory (Ormrod, 2009), which will now be discussed.

3.2.2 The social cognitive theory

The social cognitive theory (SCT) is a "theoretical framework for analysing human motivation, thought and action" (Bandura, 1986, p. xi) and has been applied extensively by those interested in teaching and learning (Ormrod, 2009; Schunk, 2004). SCT stresses that much learning takes place in a social environment through what is called "observational learning" and explains human functioning in terms of a "triadic reciprocality" – the interaction between environmental influences, cognitive and other personal factors, and behavior. Observational learning and triadic reciprocality will now be discussed.

3.2.2.1 Observational learning

By watching the performance of other people (models) and the consequences of their actions, a person forms rules for his or her own behavior that serve as a guide for future action (Bandura, 1986). People do not only learn by observing live models, but also from symbolic or nonhuman models (cartoon characters), from electronic media such as television and video and from verbal instruction in printed material such as books (Ormrod, 2009; Schunk, 2004).

Cognitive skills can be learned by observing a skilled person demonstrating the skill while verbalizing his or her thoughts and reasons for performing certain actions. Research on teaching long division has shown that modelling, combined with explanation is more effective than explanation alone. The person demonstrating the skill can also include reflective statements during the demonstration such as “This is a difficult step”, or “I’m doing well” (Schunk, 2004). Learning a complex skill can further be enhanced by allowing students to perform the skill and giving them feedback. The feedback will enable them to identify aspects they might have missed and give them the opportunity to correct their mistakes (Schunk, 2004).

Many skills, like long division mentioned in the previous paragraph, are performed using known procedures. During design and solving ill-defined problems, it may be necessary to generate new and innovative procedures (Jonassen et al., 2006) requiring a deep understanding of the concepts and rules governing the particular activity (Könings, Brand-Gruwel, & Van Merriënboer, 2005). According to Bandura (1986), abstract modelling can be used to teach difficult concepts and rules. During abstract modelling, students observe the actions relating to a specific concept or rule. The actions differ for nonrelevant facets, but the rule or concept for the essential characteristic remains the same. Students can later demonstrate their mastery of the rule or concept in a situation that is new and unfamiliar to the extent that they cannot simply mimic the behavior previously observed (Bandura, 1986, p. 100).

Even though the lecturer is an obvious model during observational learning, students can also learn from observing each other (Boud et al., 2014). The role played by the group in the facilitation of learning is described in more detail during the discussion of social constructivism.

3.2.2.2 Triadic reciprocality

Human functioning is explained according to a model “in which behavior, cognitive and other personal factors, and environmental influences all operate as interacting determinants of each other” (Bandura, 1986, p. 18) as shown in Figure 3.1.

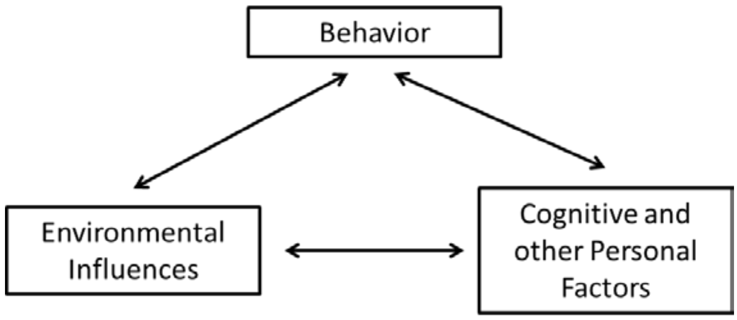

Figure 3.1: Triadic reciprocality in the social cognitive theory

Firstly, the interaction between the three factors will be illustrated. Then each variable will be considered in greater detail.

Examples of possible interactions are: When a lecturer explains a concept to the class and a student understands it, the environment has influenced the cognition of the student. When a student who does not understand asks a question, cognition influenced behavior. The environment influences behavior when the lecturer gives students a task to do. When students find they can solve the problem, their self-confidence increases (behavior influenced cognition – how they see themselves). When they ask the lecturer if they can continue with a next task and they are allowed to do so, cognition influenced behavior and by asking, the students' behavior influenced the environment (Schunk, 2004).

Even though the three variables are highly interdependent in most instances, the strength of the bi-directional influences between the three variables can vary for different situations. For instance, an environmental factor – such as perceived or real danger – will trigger the same behavior in most people regardless of their cognitive and behavioural repertoires. When the environmental sanction is weak, personal factors will dominate behavior (Bandura, 1986). It seems that Schunk (2004, p. 84) in general, do not consider the three factors as determinants of each other, but use the words "reciprocal interactions" to describe the effect that the three factors have on each other.

3.2.2.2.1 Cognition and other personal factors

Personal factors include visible aspects such as appearance, age, race and gender but also invisible aspects such as knowledge, understanding, skills, attitudes, beliefs and values (Bandura, 1986). Various personal factors play a role during problem solving.

Knowledge and understanding are obvious personal factors necessary for solving problems. Social skills are necessary to work successfully in a group.

Students need to be taught (environment → cognition) and exercise (behavior → cognition) their social skills (Collins, Joseph, & Bielaczyc, 2004). When students have the perception that they cannot succeed independently of each other positive interdependence – one of the elements of cooperative learning – is present (Johnson & Johnson, 2013). Environmental variables can be manipulated to strengthen this perception.

3.2.2.2.2 Environmental influences

The learning environment has many facets (Radovan & Makovec, 2015). An obvious aspect is the physical dimension. The physical dimension includes the nature and character of the environment in which teaching takes place and in which the student must live and learn. The learning environment also has a social dimension. The social environment includes the nature of the contact between the student and lecturer. The contact can vary from personal contact during conventional lectures to virtual contact in e-learning environments (Zhang, Fang, Wei, & Wang, 2012). A teaching-learning approach can be lecturer-centred or student-centred (Baeten, Kyndt, Struyven, & Dochy, 2010). The social dimension also includes the class room culture and the relationships between students (Fredericks, Fleming, Burrell, & Griffin, 2012). When working in groups, the group size and team members are important, if not the dominant environmental influences.

Although it may be possible to describe the objective characteristics of the environment, the effect of the environment on persons and behavior is not fixed, autonomous or automatic because personal and environmental determinants are interdependent (Bandura, 1986). Therefore, different persons will react differently to the same environmental stimulus. It is also possible to perceive the same environment in different ways. This means the perception of the environment may even have a greater effect than its objective characteristics (Radovan & Makovec, 2015). For example, students may feel at liberty to, or hesitate to participate, or ask question in class depending on their perception of what their class-mates will think of them (Zhang et al., 2012).

3.2.2.2.3 Behaviour

During group work, the desired behavior is cooperation between students that will result in learning and the development of relevant skills. Because cognitive processes cannot be observed as such, their mastery must be inferred from the behavior of the individual (Schunk, 2004). A student's problem-solving skill must be demonstrated by his or her ability to solve problems. In this specific context, where students solve problems in groups, the social constructivist theory (which deals with learning in social contexts), forms an important part of the theoretical framework and is the second facet of the theoretical framework.

3.2.3 Social constructivist theory

First constructivism will be discussed before a distinction is made between personal and social constructivism.

According to Schunk (2004, p. 286) constructivism is strictly speaking an epistemology or a “philosophical explanation about the nature of learning”. Since then it has broadened its scope and in an appraisal of constructivism, Matthews (2002) identifies eight dimensions of constructivism including constructivism as a theory of learning, as a theory of teaching, as a theory of cognition, and as a worldview – to name four. In recent years constructivism has been increasingly applied in learning and teaching and is a major theoretical influence in science and mathematics education (Baviskar, Todd Hartle, & Whitney, 2009; Matthews, 2002). In this paragraph, the focus will be on teaching and learning.

According to the constructivist view, students are active participants in the learning process and select, re-interprets and re-organizes information and experiences in order to give meaning to, and make sense of information and experiences (Ertmer & Newby, 2013; Larochelle, Bednarz, & Garrison, 1998) – in other words, construct their own individual knowledge. However, this does not mean knowledge is arbitrary.

Schunk (2004) identifies two extremes in constructivist knowledge. In exogenous constructivism, knowledge is a representation of the external world and is accurate to the extent that it reflects the external reality. At the other extreme – endogenous constructivism – new knowledge is derived from existing individual knowledge and not directly from interaction with the environment and is therefore the result of individual cognitive abstraction.

An example containing elements of exogenous and endogenous constructivism is conceptual frameworks. Whereas it is common to describe concepts as a mental representation (Bächtold, 2013), Hiebert and Lefevre (2013) also describes concepts as pieces of information in a rich network of relationships. In Chapter 2 it was shown that in thermodynamics, although concepts such as internal energy and enthalpy are rigorously and unambiguously defined, the network of relationships between them can be built up in different ways. The result is that different individuals will have different concept maps of thermodynamics.

Baviskar et al. (2009) adds personal aspects such as emotions, values, and experiences to the possible relationships in this network of relationships. Therefore, there will also be individual experiences, emotions, and values attached to concepts such as heat, work, and energy. Scientific concepts and the relationships between them will have an endogenous dimension;

private and unique to the individual, but also an exogenous dimension that can be subjected to objective scrutiny and tested for accuracy and correctness.

It is common to distinguish between two types of constructivism: *personal constructivism* associated with the work of Piaget, and *social constructivism* associated with the work of Vygotsky. Bächtold (2013) suggests that the fundamental difference between the two originates from their understanding of the development of concepts during childhood. Piaget's work focused on the development of *spontaneous concepts* – concepts that are formed by children on their own, spontaneously, and in an unconscious manner. Vygotsky focused on the development of *scientific concepts*, that is, concepts that are first developed by society and then shared with children.

Lourenço (2012, p. 292) makes a similar distinction. According to him, Piaget's theory emphasises the subject's autonomy when confronting the physical and social environment, whereas Vygotsky's dominant orientation is "to what comes from outside and is extrinsic" to the individual.

In social constructivism the individual is not autonomous, but the social group containing the individual is the unit of analysis (Bächtold, 2013; Cobb, 1996). Bächtold (2013) identifies two trends in social constructivism: Cooperation and enculturation as shown in Figure 3.2.

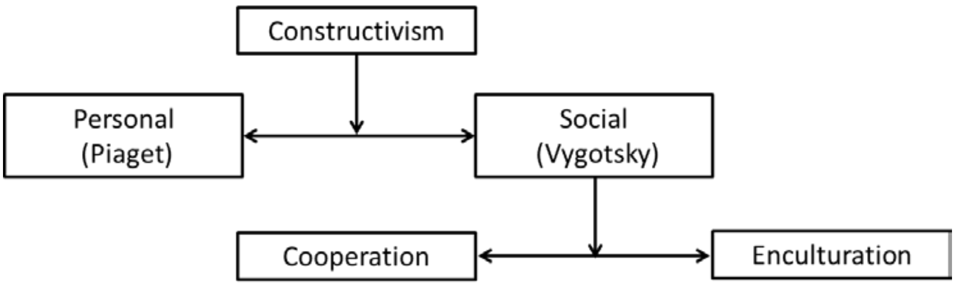

Figure 3.2: The structure of constructivism

According to Bächtold (2013) enculturation was initiated by Driver and her co-workers who stated that "learning is seen as the process by which individuals are introduced to a culture by more skilled members" (Driver, Asoko, Leach, Scott, & Mortimer, 1994, p. 7). In a teaching environment, the lecturer is typically the more skilled person. The lecturer must introduce the students to the culture and its "tools", that is, its concepts, models, and theories. Furthermore, the lecturer should also help the student to understand and master the tools.

The second trend in social constructivism, cooperation, has its origins in the study of cooperation between children. It was found that the social interactions during cooperation had a strong influence on the cognitive structure of the children. The differences in the cognitive structures of different children give rise to *socio-cognitive conflict*. It is argued that such conflict is more effective than individual cognitive conflict at stimulating the development of the child's cognitive structures (Bächtold, 2013). In similar vein, Goos, Galbraith, and Renshaw (2002) have shown that students help each other to solve problems successfully when they challenge each other's understanding and strategies and endorse useful strategies. They state that this interaction creates a *bi-directional* zone of proximal development where students can coordinate their different perspectives to make progress. A study by Forman (1989) showed how peers can help each other to include new reasoning strategies into their repertoire and found that peers can serve as teachers and students for each other.

The social interdependence theory completes the theoretical framework. According to Johnson and Johnson (2013) the social interdependence theory is the most important theory dealing with cooperation.

3.2.4 The social interdependence theory

Groups will not automatically cooperate successfully when given a task to do (Johnson & Johnson, 2013). According to Johnson and Johnson (2013, p. 89): "The basic premise of the social interdependence theory is that the type of interdependence structured in a situation determines how individuals interact with one another which, in turn, determine outcomes."

Interdependence "exist when the outcomes of individuals are affected by their own and other's actions" in the social group (Johnson & Johnson, 2013, p. 88). Interdependence can be positive or negative. Positive interdependence exits if there is a positive correlation between the achievement and success of the team members (Johnson & Johnson, 2013), in other words, a mutually beneficial situation. According to Felder and Brent (2016), positive interdependence exists if team members must rely on each other in order to be successful. Although Johnson and Johnson (2013, p. 89) state that the perception must exist that individuals' success are totally dependent on the success of the rest of the group ("individuals can reach their goals if and only if the others in the group also reach their goals"), in their description of interdependence they only mention that outcomes are "affected by own and others' actions" (Johnson & Johnson, 2013, p. 89). It therefore seems the strength of the interdependence can vary. The stronger the correlation between the achievement and success of the team members, the easier it would be to create the perception of total interdependence.

Negative interdependence exists if another persons' success impacts negatively on my own chances to succeed. This is the case when competition exists for a fixed reward and the "winner takes it all" (Smith et al., 2005). Johnson and Johnson (2013) also identify other types of dependencies. During individualistic efforts, social independence exists (when my actions do not affect the goal achievement of the members of my social group and their actions also do not affect my goal achievement). Social dependence exists when my actions do affect the goal achievement of the members of my group, but their actions have no effect on my goal achievement. When neither the individual himself nor the members of the group can help an individual, social helplessness exists.

Based on the theoretical framework discussed above, cooperative learning is a teaching-learning strategy where students work in a group and pursue a common goal (Prince, 2004).

3.3 Cooperative learning

Johnson et al. (2008) identified five elements of an effective cooperative learning environment, which will now be discussed.

3.3.1 The five elements of cooperative learning

According to Johnson et al. (2008), in order for cooperation to work well, it is necessary to explicitly structure these five elements into each cooperative session. They continue, “They are a regimen, [which] if followed rigorously, will produce the conditions for effective cooperation” (Johnson et al., 2008, pp. 6-7). These elements are

- positive interdependence,
- individual accountability,
- promotive face-to-face interaction,
- interpersonal and small-group skills, and
- group processing.

Each of these elements will now be discussed.

3.3.1.1 Positive interdependence

Positive interdependence (introduced in paragraph 3.2.4) is the most important element of cooperative learning (Johnson et al., 2008, p. 1:14; Smith et al., 2005).

According to Johnson and Johnson (2013), one condition for positive interdependence to exist is if the team members have the perception that they must coordinate their efforts to complete a task. According to *The Oxford English Dictionary* (2014) a perception *is an opinion or belief*. Sometimes, as in the example given by Johnson and Johnson (2013), in a football game of the quarterback who throws the ball and the receiver who catches the ball, both parties must coordinate their actions (and execute them adequately) for the pass to be successful.

Coordination of effort in this instance is a necessity, it is “hard wired” into the nature of the task. However, in general, coordination is not always a necessity and positive interdependence will often depend of the perception of people. Different people will perceive reality differently and the strength of perceptions (and therefore also the strength of positive interdependence) will vary accordingly.

Two major categories of positive interdependence exist: outcome and means interdependence (Johnson & Johnson, 2013). Outcome interdependence exists if a group of students strive to reach a mutual goal or reward, but on condition that each member achieve their own individual goals. Means interdependence include (a) Resource interdependence. Each member has a part of the resources necessary for success. (b) Role interdependence. Each member plays a unique, essential, and preferably complementary role that enables the group to achieve success. (c) Task interdependence. The task is divided into parts that each must be completed for the group to be successful. Johnson and Johnson (2013) also mention other types of positive interdependence (identity, fantasy, outside enemy, and environmental interdependence), which are perhaps better understood as strategies for promoting positive interdependency or require a broader conceptual understanding of what positive interdependency is.

There are different ways in which to structure positive interdependence. Giving the group challenging problems (including limited time) will encourage students to rely on each other (Felder & Brent, 2016; Froyd, 2010; Kagan & Kagan, 2009). The time constraint will encourage the division of labor with each member performing different but complementary tasks (task and role interdependence). Each student will use different but complementary resources to perform the different tasks (Resource interdependence). This in turn will provide incentive for each member to compensate for shortcomings their team mates’ knowledge and skills to enable them to perform their task and play their role better. Therefore, the better my partner is, the quicker and easier we will be able to solve the problems (Goal interdependence).

Reward interdependence can be achieved by letting the team hand in their joint effort and awarding the mark obtained to all team members (Johnson et al., 2008).

Group cohesion can be enhanced by letting the group work together in the same place at the same time (environmental interdependence) (Johnson & Johnson, 2013).

The structuring of positive interdependence takes place in the environment. The goal of this structuring is to create and strengthen the perception in the minds of the team members that they cannot succeed on their own and that they must coordinate their efforts in order to succeed

(Johnson & Johnson, 2013). This perception will result in a specific behavior, namely promotive interaction.

3.3.1.2 Face-to-face promotive interaction

According to the social interdependence theory, positive interdependence will result in students helping each other. Johnson and Johnson (2013, p. 89) states: "… the type of interdependence structured in a situation determines how individuals interact …. Positive interdependence tends to result in promotive interaction …" They further state, "Promotive interaction occurs as individuals encourage and facilitate each other's efforts to accomplish the group's goals. Promotive interaction is characterized by individuals providing each other with help and assistance, exchanging needed resources ... challenging each other's conclusions and reasoning ... and acting in trusting and trustworthy ways."

The facilitator can further structure promotive interaction by getting students to discuss the problem and explain to each other the concepts and relevant strategies (Felder & Brent, 1994; Smith et al., 2005). The facilitator should also monitor the groups and not allow a situation where one student does all the work and the other(s) is (are) passive. Also, students should be made aware of and experience how explaining a problem to a team mate and discussing the solution improves their own understanding of the problem as well as their own problem-solving skills (Whimbey et al., 2013).

3.3.1.3 Individual accountability and personal responsibility

Johnson and Johnson (2013) distinguish between group and individual accountability. Group accountability exists if the group knows how well they as group is doing compared to a standard of performance. Members of groups with a strong common purpose inevitably hold themselves, both as individuals and as group, responsible for the team's performance. Individual accountability means that students must feel and be held accountable for making a contribution towards achieving the goal of the group (Johnson et al., 2008, Felder & Brent, 2016). This means coming prepared, being involved in, and contributing to the problem-solving process.

Even while receiving help from others, students must ultimately take responsibility for their own learning and success (Johnson et al., 2008). In a group, this means making sure they understand what is going on during the problem-solving process and if necessary asking their partners, the assistant, or the lecturer for clarification. According to Felder and Brent (2016) giving individual assessments on the content of the team task is effective in ensuring individual accountability. Individual assessments enable the student to learn together to be able to better perform as individual.

Accountability is structured in the environment by establishing a strong common goal and assessing the individual's performance.

3.3.1.4 Interpersonal and social skills

For a group to function properly members must have the skills necessary to work together. When students apply these skills, it leads to positive relationships (Johnson & Johnson, 2013). These skills become more important as the group size increases (Johnson et al., 2008), if the group stays together for an extended period of time, or works on complex assignments (Johnson & Johnson, 2013).

Students must be taught these interpersonal and social skills (Johnson et al., 2008) and, as with other skills, must be accorded the opportunity to exercise and improve them. Skills include conflict resolution, communication (learning to talk, learning to listen), trust building (getting rid of stereotypes, delegation), decision making and leadership (the ability to lead and to follow, as well as compromise) (Smith et al., 2005).

3.3.1.5 Group processing

Groups should reflect on how they are doing as a group and how they can improve (Johnson et al., 2008). Johnson and Johnson (2013, p. 107) specifically mention that the group should reflect on their work processes and interaction between members, what actions were helpful and what action were not. When groups meet more than once, this reflection will be especially important to ensure effective functioning of the group.

Felder and Brent (2016, p. 247) describe group processing as students periodically assessing their progress towards the group goal. In order to develop their problem-solving skills, students should also receive feedback on how well they solved the problem and be given the chance to discuss how the problem could be solved differently (Whimbey et al., 2013).

The nature or "design" of the problems that groups must solve determines whether this review and feedback process during group processing will be effective or even possible. For instance, writing is inherently an individual activity. If the goal of the assignment is therefore to produce a report, the group will most probably divide the work between the team members and complete each part individually (Michaelsen & Sweet, 2011). Complex write-ups also take considerable time to mark, by which time the student has most probably moved on to new work and forgot about the assignment, reducing the effectiveness of reflection and review (Hodgson, Ostafichuk, & Sibley, 2005). This brings into focus the importance of the nature of problems that is solved by groups.

3.3.2 The nature of effective group problems

Properly designed problems can result in cohesive groups where synergistic interaction (Olson, 2005) and effective review can take place (Hodgson et al., 2005). Barkley, Cross, and Major (2005), and Felder and Brent (2016, p. 256) recommend making the task sufficiently complex to encourage broad participation within the group. Michaelsen and Sweet (2008, p. 41) recommend that the group must be required to “make a concrete decision based on the analysis of a complex issue”. Hodgson et al. (2005) expected students to report a simple result which required extensive analysis and discussion.

In order to promote discussion between groups, Michaelsen and Sweet (2011) recommend that all groups receive the same problem to solve. Discussion between groups provides a convenient opportunity to obtain quick feedback and advice. Having groups work on the same problem with a result that is easy to report, makes it possible to use in-class reporting of results. The answers can now be used as the basis for a discussion or remedial instruction as necessary. After reporting their results, Hodgson et al. (2005) allowed groups to ask each other questions and challenge their methods. The group who survived the most challenges received the highest mark. This public defence of their work increased the motivation of students. Michaelsen and Sweet (2008) recommend that all groups report their results simultaneously to prevent groups of adjusting their answers.

The functioning of the group is also dependent on the size of the group as well as the attributes of the individual members. How the group is formed is therefore also important.

3.3.3 Formation of groups

Two aspects are important when forming groups: the size of the group and the selection of partners.

Usually three types of groups in cooperative learning are distinguished: cooperative base groups, formal cooperative learning groups and informal cooperative learning groups. Cooperative base groups stay together for extended periods – typically a year. The primary purpose of base groups is for members to provide support, encouragement and help to each other in order to progress academically (Johnson et al., 2008). In this study, the goal is to promote learning during tutorials that typically last a few hours and therefore base groups will not be considered.

Informal cooperative learning groups are ad hoc groups that stay together for a time period lasting a few minutes to a whole period (Johnson et al., 2008). If a group only stay together for a few minutes, the most practical approach is for students to self-select their partner(s), or pre-form groups and let students work in the same group every time. For thinking aloud pair problem solving, Whimbey et al. (2013) recommend that students should work with different partners a few times before they are allowed to choose a partner.

Great care must be taken in forming groups that will stay together for longer periods to ensure that that the group members have the skills necessary to perform the task. It is therefore necessary to form groups that are heterogeneous and diverse (Michaelsen & Sweet, 2011). Individuals should be selected for their ability (or potential ability) to perform the necessary task and not for instance their position or personality (Johnson et al., 2008). Care should also be taken to prevent the possibility of coalitions or subgroups forming – for instance students staying in the same residence being in the same group (Michaelsen & Sweet, 2011).

Students should therefore not be allowed to form their own groups as they may not be aware of the attributes of different students or they may form self-serving groups (Michaelsen & Sweet, 2011). Johnson et al. (2008, p. 2:6) see student-formed groups as the “least recommended procedure” and recommend random allocation of students to groups.

Johnson and Johnson (2013, p. 452) discuss several aspects that should guide the decision on group size. If time is limited, smaller groups should be used. Smaller groups are quicker to form. It is easier for a small group to organize themselves and the time available for interaction per member, is increased. Keeping the group small makes it easier to detect individual members not contributing and will encourage students to come prepared and contribute (Johnson et al., 2008).

Smaller groups therefore promote individual accountability. In smaller groups, there are fewer relationships and interactions to manage and it is easier to identify problems related to cooperation. On the other hand, an advantage of larger groups is that each additional member can contribute unique resources and abilities increasing the available repertoire of knowledge and skills.

The environment may play a determining role in group functioning. Heller and Hollabaugh (1992) investigated the effect of group size for groups solving ‘context-rich problems’ – problems that are not as well-structured as problems typically encountered in introductory engineering science courses. They varied the number of group members between two and four. They found that groups of three performed better. Because the problems were challenging, it seemed that three heads were better than two. The third member could suggest alternatives when the group became stuck and helped to resolve conflict. In groups of four, the fourth member was often left out of the problem-solving process – especially timid students. They found that groups of three were large enough to generate diverse ideas but small enough so that everyone could take part and benefit – as long as they could face each other. However, when three students sat side-by-side, the third student was often left out.

Kooloos et al. (2011) compared groups of fifteen students working together to three groups of five students working on subtasks of the same task. After completion of the subtasks, the three groups met and peer-teaching took place. The students preferred working in small groups on smaller tasks.

Bilgin (2006) had students solve chemistry problems using Polya's problem-solving strategy and compared students working individually to students working in pairs according to the principles of pair problem solving. He found that the forty-four students working in pairs performed better than the students working individually.

3.4 Solving problems in pairs

In the following section, two well-developed strategies where students work in pairs, pair problem solving and pair programming, are discussed.

3.4.1 Pair problem solving

Whimbey and Lochhead (1979) introduced pair problem solving which later became known as Thinking Aloud Pair Problem Solving (TAPPS) (Whimbey et al., 2013). The two members of the groups have specific roles.

The problem solver must verbalize his or her thoughts while solving a problem while the listener continually check accuracy, makes sure he or she understands the problem solver's reasoning and demands constant vocalization by the problem solver. Richard Felder has done much work to promote active learning and are of the opinion that thinking pair share and thinking aloud pair problem solving are particularly effective strategies (Felder & Brent, 2003, 2009).

3.4.2 Pair programming

Williams and Kessler (2003) developed pair programming as a formal collaborative strategy for computer programming where one member (called "the driver") is operating the keyboard and the other (called "the navigator") is watching and checking, paying attention to the overall design. The navigator and driver rotate their roles regularly. Pair programming was implemented with success in the teaching of computer programming by Williams and Upchurch (2001). Mentz et al. (2008) found the effectiveness of pair programming as a teaching-learning strategy could be improved by the incorporation of the elements associated with cooperative learning as described by Johnson et al. (2008).

Williams and Kessler (2003) discuss several synergistic behaviours of persons working in pairs. Firstly, working in a pair puts a positive form of pressure on each member of the pair to focus on the task and to contribute to the task. Familiarity between team members may reduce this pressure and therefore it is best if students are not allowed to choose their own partners (Felder, Woods, Stice, & Rugarcia, 2000; Johnson et al., 2008). Students will be more willing to admit their ignorance, or venture a suggestion, to a fellow student than to the lecturer or the whole class (Williams & Kessler, 2003). A student working alone is more likely to quit when encountering problems (Johnson et al., 2008). Another advantage is synergy (Williams & Kessler, 2003). Each member of the pair can contribute their understanding and complement the other partner, and in the process, increase their chances of solving the problem.

When two students cooperate on solving a problem they can perform all three steps necessary for the development of their problem-solving skills: demonstration, practice, giving and receiving feedback (Felder & Brent, 2003; Heller et al., 1992; Whimbey et al., 2013).

3.5 Summary

In this chapter, a theoretical framework for a cooperative learning procedure where students work in groups of two was proposed. The theoretical framework consists of three theories and is shown in Figure 3.3.

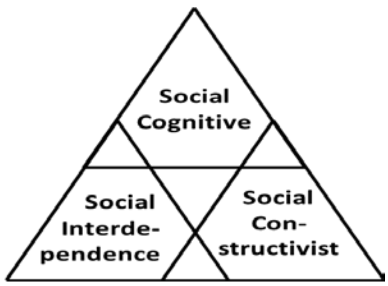

Figure 3.3: The three theories forming the theoretical framework

The social cognitive theory of Albert Bandura explains human functioning in terms of the interactions between three factors: behavior, environmental influences, and personal factors such as cognition and perceptions. In the context where students solve problems together, the desired behavior is that the individuals in the group co-operate effectively – in other words, in such a way that learning takes place. To promote the desired behavior the students must have the perception that they need to coordinate their efforts to succeed. The environment is manipulated to strengthen this perception. For instance, the problems are made challenging and the two students receive the same credits for their joint effort.

The social interdependence theory also deals with cooperation. When positive interdependence exists, students will help each other to reach individual and team goals. Johnson et al. (2008) identified five elements necessary for effective cooperation. These five elements constitute their version of a practice known as cooperative learning. The most important element is positive interdependence. The others are face-to-face promotive interaction, individual accountability, group skills, and reflection on group functioning. Two operational aspects that support the structuring of the elements of CL, are problem selection and group formation.

The third theory of the theoretical framework is the social constructive theory. According to the constructivist view, during learning the student is an active participant and selects, re-interprets and re-organizes information and experiences to give meaning to, and make sense of information and experiences. When students work together, they can learn from each other and this interaction creates a bi-directional zone of proximal development where students are able to coordinate their different perspectives to make progress.

Pair problem solving and pair programming are examples of strategies where students collaborate in groups of two – but without a conscious effort to structure the elements of CL into the strategy. In the next chapter, the steps of a procedure are described where students work in groups of two – cooperative pair problem solving (CPPS).

CHAPTER 4
RESEARCH METHODOLOGY AND DESIGN

4.1 Introduction

In Chapter 3 the theoretical framework was laid for a CL strategy where students work in groups of two (CPPS). In the chapter that follows, based on the theoretical framework developed in Chapter 3, the intervention, in other words, the specific steps that are taken during the tutorial with the implementation of this strategy are described. Before the intervention is discussed, the research methodology followed to answer the research subquestions are motivated and described in detail. The following aspects are covered: the research paradigm, the research design, and the methodologies of the qualitative and quantitative investigations.

4.2 Research paradigm

Morgan (2007) identified four versions of the paradigm concept found in research literature. The versions are nested within each other and are not mutually exclusive. The first version is paradigms as *worldviews*. He describes a worldview as an “all-encompassing way of experiencing and thinking about the world” (Morgan, 2007, p. 50). He believes that this version of a paradigm is too wide to be useful in research, because a worldview, in his opinion, includes a person’s beliefs about virtually everything. The second version is paradigms as *epistemological stances*. Epistemology is the explanation of the nature of knowledge with specific reference to the scope and validity of such knowledge *(Merriam-Webster dictionary*, 2014). Epistemology is one of three intimately related elements (Krauss, 2005; Schnelker, 2006) in a common taxonomy used to distinguish between paradigms – the other two being ontology and methodology.

The approach of seeing paradigms as epistemological stances, highlights the differences between, for instance, qualitative and quantitative methods and may not be the most appropriate way to select appropriate methodologies if the objective is to answer a specific question (Krauss, 2005). It may be more productive to focus on the phenomenon.

Focusing on the phenomenon is compatible with the third version of paradigms which entails shared beliefs, assumptions, practices, concepts, and values held by a community of researchers (Johnson & Christensen, 2014; Morgan, 2007). This is also the version preferred by

Kuhn (1970). The fourth, and narrowest version, is paradigms as *typical examples of research* and is used mainly in the discussion of examples of research in a specific field.

Morgan (2007) uses the third version of paradigms, shared beliefs, as the foundation to build the case for the pragmatic approach – the approach that will be used in this study.

The pragmatic approach seeks to transcend three dualisms (Morgan, 2007). In the first place, the position of the researcher can vary on a continuum between objectivity and subjectivity. In this study, I, the researcher, was part of the process in the sense that I implemented the cooperative pair problem-solving strategy (CPPS), but was not part of the interaction between students while they solved the problems together. Secondly, in the pragmatic approach it is possible to place the inferences made from the data between the extremes of context-dependent and specific on the one hand, to universally applicable on the other. Even if this study was conducted in a thermodynamics class, the knowledge gained should also be relevant during the implementation of CPPS in other engineering science and pure science courses. In the third place, in the connection between data and theory, both induction and deduction can be used to connect data and theory. The framework described in Chapter 3 acts as the theoretical base for the design of the CPPS intervention (deduction) while the data generated during the implementation will make it possible to comment and formulate hypotheses about the efficacy, implementation, and structure of CPPS (induction). Pragmatism endorses an empirical approach to determine what works (Johnson & Christensen, 2008), which suits this study well as it was implemented during actual tutorials and the effects evaluated.

Furthermore, the pragmatic approach focuses on the question and uses all available strategies necessary to understand and answer the question (Creswell, 2014b). The pragmatic approach therefore enables the researcher to use multiple methods. In this study, the first research sub-question was answered by drawing from the body of scholarship on CL and in order to answer the other research subquestions, empirical data was collected using qualitative and quantitative methods.

4.3 Empirical investigation

First the locality and then the design of the empirical investigation is discussed.

4.3.1 Locality

The study was performed at two South African universities presenting four-year degree courses in Engineering. Both universities have faculties spanning a wide spectrum – from arts and social sciences, economic sciences, law, natural sciences, and engineering. Each of the universities has more than 20000 students on the respective campuses enrolled full-time for the different degree programs in these faculties.

The engineering qualifications from both universities are accredited by the Engineering Council of South Africa (ECSA) which is a signatory to the Washington Accord, the Sydney Accord, and the Dublin Accord. University A presents engineering degrees in six disciplines and University B in three. The student population consisted of the students taking their first introductory course in mechanical engineering thermodynamics. The course at both universities is known only as Thermodynamics. It is distinguished by the course code from other courses in thermodynamics (each with their own unique scope and content) presented by other departments and in other faculties. At University A, both the process and mechanical engineering students took the course in mechanical engineering thermodynamics. I was given the opportunity to implement CPPS at the tutorials of University A. Except for students repeating a subject attendance of all tutorials was compulsory at this university. The Afrikaans and English groups were lectured separately. At University B, only mechanical engineering students took the introductory course in mechanical engineering thermodynamics. I was also the lecturer for this group. Lectures were presented in Afrikaans with whisper translation available to the few English-speaking students. Attendance of thermodynamic tutorials at this university was never compulsory and in order not to introduce another variable it was decided to make the attendance of the CPPS tutorials voluntary again during the year that CPPS was implemented.

4.3.2 Research design

The goal of the empirical part of this study was to determine how successful CPPS was. Two aspects of success were considered.

The first aspect focused on the *perceptions* of the students and role players. For example: How successful was the structuring of the five elements of CL in their view? How did students experience CPPS? Was it successful in their opinion? From the instructor's point of view, it was also important to know whether CPPS is a viable strategy and practical to implement. Different aspects are addressed by research subquestion 2 and 3, and were answered using a convergent parallel mixed methods design (Creswell, 2014b).

Mixed methods designs have three dimensions (Bryman, 2012; Creswell, 2014a): (a) The intent of combining quantitative and qualitative data. By combining methods, it is possible to compensate for the weaknesses and utilize the strong points of qualitative and quantitative methods. Also, the quantitative data can provide precision as well as strengthen evidence where convergence between the methods exists (Johnson & Onwuegbuzie, 2004). (b) The timing of collecting the qualitative and quantitative data. In this method, qualitative and quantitative data were collected independently from each other, from the respective study populations during the semesters that CPPS was implemented. (c) Emphasis or weight placed on the different types of data. For the mixed methods design used in this research, the qualitative results carried more weight than the quantitative results.

The second aspect involved the *outcomes* of the process: Does the strategy influence the students' academic performance and conceptual understanding? These aspects are addressed by subquestion 4 and 5 and were answered using two quantitative methods, a quasi-experiment, and a correlational analysis. For the quasi-experiment, data was collected from the year groups (2012) not exposed to CPPS as well as the year groups (2013) exposed to CPPS at both universities. For the correlational analysis data on tutorial attendance and academic performance at University B were collected from 2013 till 2105.

For the study, both the quantitative and qualitative results are important. For instance, it is important to know how the students feel about CPPS as well as how CPPS affects academic performance. However, the focus of the study is on CPPS as a CL strategy and more weight is therefore placed on the results from the convergent mixed methods parallel design focussing on the perceptions of the role-players.

A schematic presentation of the empirical research appears in Figure 4.1 and is discussed in detail afterwards. An A or B indicates the respective universities.

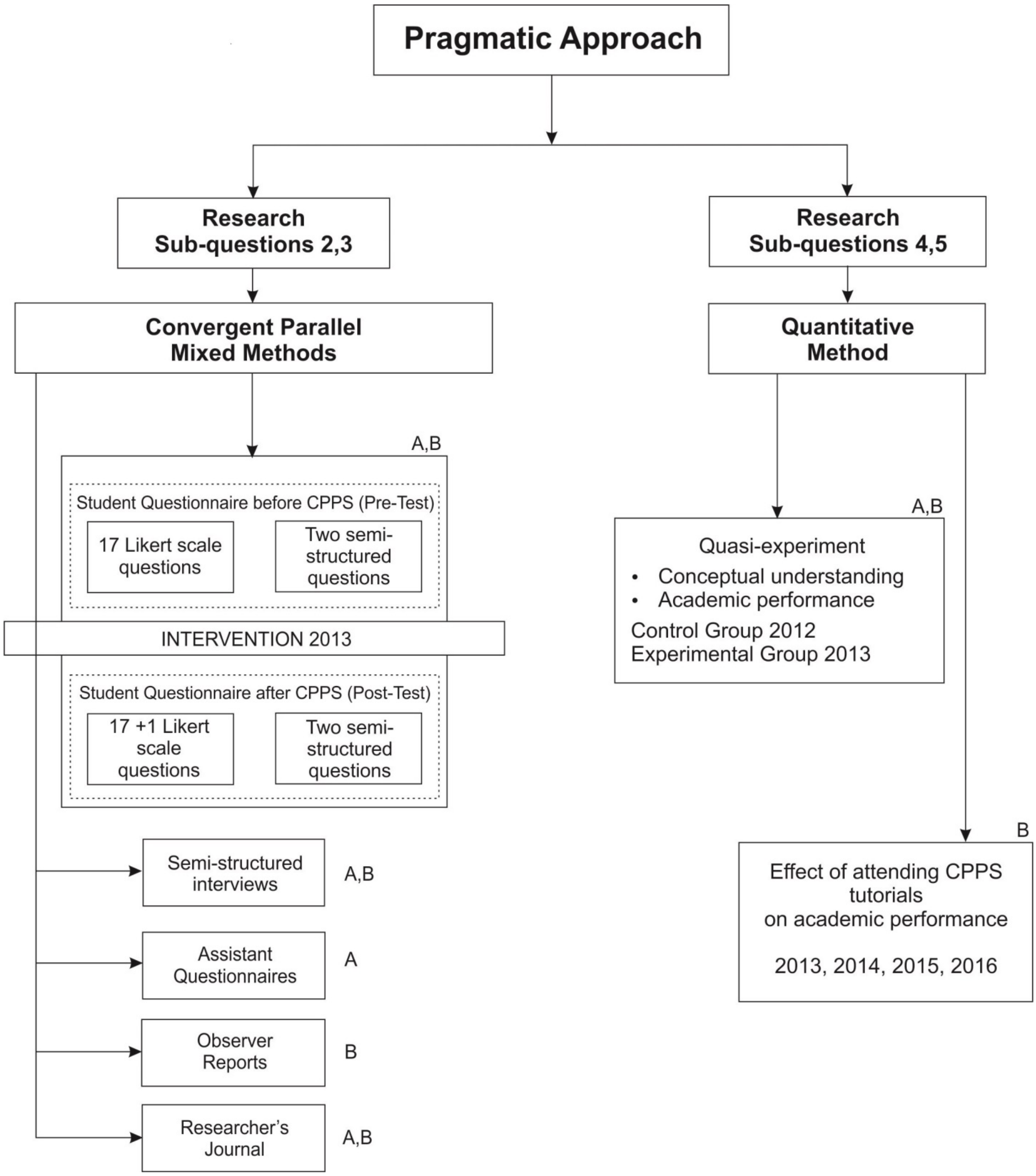

Figure 4.1: Diagrammatic presentation of research

4.4 Answering the research subquestions

As mentioned already, the first research subquestion is answered by drawing from the body of scholarship. The answering of subquestions 2 to 5 will now be discussed.

(a) Research subquestion 2: How successful was CPPS with regards to the structuring of the five elements of CL?

This question is considered from two perspectives. The first perspective is of the students who are solving problems in groups of two and the second perspective from the people observing this cooperation: the student assistants, the outside observers and I, the researcher. Information about the students' perspective is obtained from qualitative and quantitative measurements in the student questionnaire, while the perspective from outside is only qualitative information. These sources of information are shown diagrammatically in Figure 4.2. (The paragraph number where the specific aspect is described appears in brackets.)

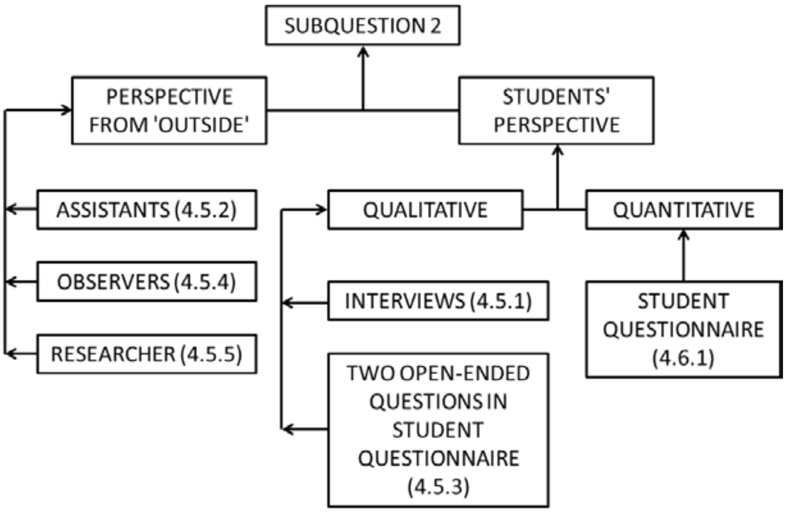

Figure 4.2: Perspectives on the structuring of the elements of CL during the implementation of CPPS during tutorials

(b) Research subquestion 3: What are the different role players' perceptions of CPPS?

Apart from the structuring of the five elements of CL, the success of CPPS is dependent on other aspects as well. For instance, from the literature it was clear that students may resist procedures such as CPPS and that a CL strategy may require extra work to implement. To determine the success of CPPS, it was therefore also important to determine the perceptions of CPPS of the different role players of CPPS (apart from the structuring of the five elements). The same sources of data as in Figure 4.2 is used.

(c) Research subquestion 4: What is the effect of CPPS on the academic achievement of the students?

To answer this question, a quasi-experiment was used as it was not possible to divide the 2013-year group into a control and experimental group.

There would have been ethical problems associated with a true experiment which divided the students of the same year into a control group and experimental group especially since during the development stages, the advantages of a cooperative approach were evident (Van Niekerk & Mentz, 2013; Van Niekerk, Mentz, & Smit, 2011). There were also practical concerns. At University A, the class was already divided into English- and Afrikaans-speaking groups. A true experiment would have resulted in four groups: an English control and experimental group and an Afrikaans control and experimental group. This was not practical due to personnel constraints and the availability of lecture rooms. At University B, there was only one lecturer available for supervising the tutorial, which made the division of the same class in to a control and experimental group impractical. Therefore, the final marks obtained by the 2012-control groups at the two universities, who were not exposed to CPPS, were compared to the final marks obtained by the 2013 experimental groups, who were exposed to CPPS.

Also, as the CPPS strategy was now used every year during thermodynamics tutorials at University B, data on tutorial attendance and academic performance were available for the 2013, 2014, 2015 and 2016 academic years. This data was used in a correlational analysis to determine the effect that attending CPPS tutorials had on the academic performance of students in those years.

(d) Research subquestion 5: What is the effect of the strategy on students' understanding of thermodynamic concepts?

A quasi-experiment was used to answer subquestion 5 for the same reasons a quasi-experiment was used to answer subquestion 4. The scores obtained in a concept test by the 2012 control groups were compared to the scores obtained in the same test by the 2013 experimental groups.

The qualitative data gathering and quantitative data collection procedures will now be discussed. This will be followed by a discussion of the trustworthiness of the results as the steps taken to ensure the trustworthiness of the research for the different procedures, are common to several measurements.

4.5 Qualitative research

Qualitative data was obtained from five sources: student interviews, two open ended questions at the end of the student questionnaire, six open ended questions in an assistant questionnaire, the researcher's journal, and the observer reports. Each of these qualitative sources will now be discussed in more detail.

4.5.1 Student interviews

The goal of the interviews was to determine students' perceptions of CPPS and specifically from their point of view, how successful the five elements of CL were structured in CPPS. The interviews were semistructured. According to Kvale and Brinkmann (2009, p. 27) "the semistructured life-world interview attempts to understand themes of the lived everyday world from the subjects' own perspectives." This type of interview combines phenomenology and hermeneutics (the interpretation of meaning) in a pragmatic way to establish how to conduct and analyse interviews.

Phenomenology aims to find the essence or structure of an experience from the perspective of those who had the experience. In phenomenology, the interviewer has to temporarily put aside ("bracket") other possible explanations such as his or her own personal attitudes and beliefs regarding the phenomenon (Johnson & Christensen, 2008).

4.5.1.1 Population and selection of interviewees

The interviewees were selected from the 2013 experimental groups, shown in Table 4.1.

Table 4.1: Student population of the 2013-year groups

	University A. Afrikaans	University A. English	University B.
Number of students	156	148	239
African / Coloured / Indian / White (%)	2 / 2 / 0 / 96	13 / 8 / 4 / 75	2 / 1 / 1 / 96
Female / Male (%)	18 / 82	13 / 87	8 / 92

4.5.1.1.1 Number of interviews

The guiding principle in deciding on the number of interviews during nonprobalistic sampling is the concept of saturation – the point where you have identified the major themes and new information will most probably not add new themes or significant new detail to existing themes (Creswell, 2014a). Although conceptually handy, the saturation principle does not provide guidance in how many interviews will lead to saturation. Mason (2010) studied 2,533 PhD theses and found that the number of interviews varied between 95 and 1, with a mean of 31 and a standard deviation around the mean of 18.7. Guest, Bunce, and Johnson (2006, p. 79) state: "For most research enterprises, however, in which the aim is to understand common perceptions and experiences among a group of relatively homogeneous individuals, twelve interviews should suffice."

However, they warn that a group that is relatively heterogeneous may adversely affect the quality of the data. Furthermore, if the domain of enquiry is vague or diffuse, more interviews may be necessary. Mason (2010) mentions that a study with a narrow scope employing more than one method will require relatively fewer interviews, while a heterogeneous population will require relatively more interviews. In the light of the factors affecting the number of interviews mentioned above the study population of this study will now be considered.

The composition of the 2013-year groups has already been shown in Table 4.1. The study population is predominantly white male students. Furthermore, the research takes place in a single, specific course, specifically the first course in Thermodynamics. It is therefore not a diverse group taking many subjects. Secondly, this is a mixed methods study. The interviews are therefore not the only source of data. The information from the interviews is used together with the results from the questionnaires to answer the research subquestions. In the third place, the goal of the interviews was to determine students' experiences of CPPS during a single event: the tutorials. It is therefore not a scenario with many dimensions. All these factors indicate that a smaller number of interviews should be sufficient.

It was therefore decided to do twenty-one interviews: fourteen from University A (6% of the total population) that consisted of two tutorial groups, and seven from University B (4% of the total population) where there was only one tutorial group. This number made it possible to randomly select and invite a representative number of male and female students for interviews. While it is not normally required, in order to have the participants better reflect the demographics of the group, after a representative number of white interviewees were randomly selected, the remaining interviewees were randomly selected from a combined African Coloured, and Indian group.

Each interviewee was sent an invitation by email. The email explained the goal and structure of the interview and that participation is voluntary. The invitation email, as well as my welcome to the interviewees before the interview commenced, appear in Appendix B.

4.5.1.2 Interview questions

The goal of the interviews is to (1) determine students' perception of CPPS and (2) the extent to which students experienced the five elements of CL during their cooperation. Therefore, the interview guide approach (Johnson & Christensen, 2008) was used.

An interview protocol with several open-ended questions was prepared beforehand and was used to keep the interview focussed.

The questions were:

(a) Share with me your experience with regard to the practice of working together in groups of two during the tutorial?

(b) In the students' questionnaire, many people indicated that they would not like to work in groups of two again in a next course. Would you like to speculate on possible reasons for this response?

(c) What contributed the most to your understanding of the problems during the CPPS sessions?

(d) Tell me about your approach towards solving a problem during a CPPS session?

(e) If so, what problems did you experience during the CPPS sessions?

The aim of question (a) and (b) was to try to determine the experience of students during, and attitude towards CPPS. It was aimed at understanding their experience of the strategy itself. Question (b) was not part of the original set of questions. The students' questionnaires were completed just before the interviews took place. An analysis of the students' answers to the question in the questionnaire revealed that an unexpectedly large number of students strongly disagreed with the statement, "I would like to work like this again in a next subject". The interviews presented an opportunity to gain some understanding of this reaction and therefore question (b) was included in the original question set. The inclusion of this one question was not sufficient to change the character of the method and the design remained a convergent parallel mixed methods design.

The aim of questions (c) and (d) was to gain some understanding of students' interaction and problem-solving behavior and whether they benefitted in working with someone else. Question (e) was not always asked as students usually already mentioned problems they experienced.

I conducted all the interviews. The interviews had a conversational character and follow-up questions were asked to clarify meaning, confirm, and verify my understanding and further explore the meaning of what the student said.

4.5.1.3 Analysis of interviews

A linear hierarchical approach (Creswell, 2009) was used in the analysis of the data. The following steps were followed.

All interviews were audio recorded. A general impression of the data and the students' perception of CPPS were obtained by listening to the recordings. Then the interviews were transcribed. The researcher transcribed some of the interviews himself. To protect the identity of the interviewee, the name of the interviewee was replaced with an alphanumeric code. An outside party checked the transcriptions to make sure they were accurate text renditions of the interviews. The researcher then coded the transcriptions. As described in the next paragraph, a-priori themes (Bernard & Ryan, 2010) as well as content-driven themes were used.

The students' perception of the structuring of the elements of CL during CPPS is part of their overall perception of CPPS. The elements of CL were taken as a-priori themes in the analysis of the interviews for this aspect. In order to determine other aspects of the students' perception of CPPS, themes were derived empirically from the interviews (Bernard & Ryan, 2010; Kvale & Brinkmann, 2009) as shown in Figure 4.3.

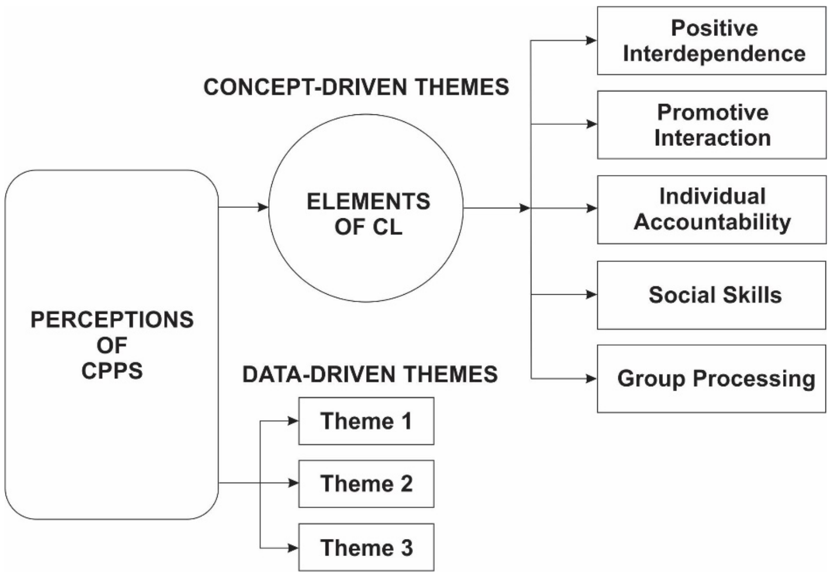

Figure 4.3: Concept and data-driven themes in the analysis of the interviews

The transcripts of the interviews of the two universities were coded separately. First the transcriptions were read to develop an overall picture. The text was then coded using ATLAS Ti. First relevant words and phrases were assigned descriptive labels. As the coding progressed, the researcher developed a better understanding and a clearer view of the students' perceptions and terms.

The codes were then grouped under the appropriate themes as shown in Figure 4.3. The transcriptions were coded a few times before convergence was reached and a clear picture of the connection and relationships (hierarchical or otherwise) between codes emerged.

4.5.2 Assistant questionnaire with open-ended questions

Three assistants were present during each tutorial session at University A. They officiated on a rotating basis.

4.5.2.1 Participants

The resident lecturer responsible for supervising the English-speaking group at University A, as well as all the teaching assistants were asked to complete a questionnaire with several open-ended questions. The ten assistants were all postgraduate engineering students who recently did the thermodynamics course. The assistants were therefore familiar with the course material, the situation and dynamics during tutorials and were therefore well qualified to be trustworthy observers. Furthermore, there was no formal or work-related relationship between the researcher and assistants or the resident lecturer. The researcher would therefore not be in any position to disadvantage any of these individuals for giving a negative or critical opinion.

4.5.2.2 Questions

The questions were

(a) What do you think of the way in which the tutorial was structured?

(b) What did you observe with regards to cooperation between students?

(c) To what extent do you think CPPS gave a student the chance to dodge his or her personal responsibility of contributing towards solving the problems?

(d) What did you observe with regards to the students' interpersonal and social skills in the groups they were working in?

(e) How do you think the students feel about CPPS? Please elaborate.

(f) What is your opinion of CPPS? Please elaborate.

Question (a) is an open-ended question which allows respondents to give their opinion of the implementation of CPPS. Question (b), (c) and (d) each focus on a different element of CL, promotive interaction, personal responsibility, and social skills. The previous three questions required from the assistant to comment on behavior. In Question (e) the assistants had to comment on their interpretation of student behavior and feelings. They were intimately involved with the implementation of the procedure. They helped with random seating, answering questions during the tutorial, taking in and marking tests. They are still students themselves and not much older than the students doing the tutorial. From their interaction with the students and the students' behavior they should therefore have been able to make a reasonably accurate judgement of the feeling of the students on CPPS. The last question is an open-ended question allowing assistants to give an opinion from their perspective. (See Appendix C for the invitation and the attached Word document containing the questionnaire, sent to the assistants).

4.5.2.3 Analysis of answers

The answers to the questions were analysed using ATLAS Ti. The codes and themes for Question (a), (e) and (f) were derived from the data. For the three questions related to the elements of CL, the themes were defined by the question but the codes were derived from the data.

4.5.3 Two open-ended questions at the end of the student questionnaire

The questionnaire contained a quantitative section with several Likert-scale questions (see paragraph 4.6.1) followed by two qualitative, open-ended questions.

4.5.3.1 Participants and sampling

All students of the 2013-year groups shown in Table 4.1 were asked to complete the student questionnaire at the end of the semester after their exposure to CPPS. To provide a baseline of their experience of working together, they were also asked to complete the same questionnaire at the first meeting with the researcher, before their exposure to CPPS.

4.5.3.2 Student questionnaire questions

The following two questions appeared after the Likert-scale questions in the questionnaire:

(a) If relevant, please provide example(s) of something that you have learned because of CPPS that you would not have learned if you were working alone.

(b) If relevant, give an example of a problem experienced by a CPPS group to which you belonged, and explain how the problem was solved (if at all).

The first question gives the student the opportunity to reflect on a positive aspect of CPPS and the second question to provide an example of a problem he experienced during CPPS. In the questionnaire student filled in before their exposure to CPPS, the word *group work* was used instead of CPPS.

4.5.3.3 Analysis of answers

The responses of the students to these questions were typed into a spread sheet and codes and themes derived from the data and indicated in the adjacent columns.

4.5.4 Observer reports

To provide an objective view of the cooperation between students and the implementation of CPPS at University B, external observers (one from the Faculty of Education and the other from the academic support department, both with PhDs in Education) attended a tutorial session and documented their observations of the activity during the tutorial sessions. It was possible to code the reports on the hard copy printouts. Themes related to cooperation and the elements of CL were used as a-priori themes during coding.

4.5.5 Journals

I kept a journal of the implementation at both universities. The journals were sequential and fragmented. Therefore, based on the journals, I wrote my memoirs of the implementation of CPPS at both universities. The memoirs contain my experiences and comments of all aspects related to the implementation of CPPS and appears in Appendix D. The memoirs were coded using ATLASti. Codes and themes were derived from the data.

This concludes the discussion of the qualitative data gathering and analysis.

4.6 Quantitative research

Quantitative data were obtained from the Likert-scale questionnaires, the quasi-experiment to determine the effect of CPPS on conceptual understanding and academic performance as well as correlational analysis of the records of academic performance and tutorial attendance at University B for 2013, 2014, 2015 and 2016. All statistical analyses were performed by the statistical consultation service of University B. (See Appendix E.)

4.6.1 Likert-scale student questionnaire

The Likert-scale questions formed the quantitative part of the mixed methods procedure and appeared first in the student questionnaire. The goal of the student questionnaire was to determine the students' experience and perception of CPPS.

4.6.1.1 Population and sampling

The questionnaire was completed by the students of the experimental group (see Table 4.1) before and after their exposure to CPPS (see Figure 4.1). The students were asked to complete the questionnaire at the first class meeting between the students and the researcher. At the end of the semester, the same students were asked to complete the questionnaire again.

The questionnaires used before and after exposure to CPPS were identical except that in the questionnaire filled in after exposure to CPPS, the term *group work* was replaced by the term *CPPS*. The data gathered from the questionnaire filled in before exposure to CPPS provided a baseline against which to measure students' perceptions of CPPS. The complete questionnaires appear in Appendix F and G.

4.6.1.2 Compiling the questionnaire

On both questionnaires students were also asked to provide their student registration numbers to facilitate linking each student's answers before and after their exposure to CPPS. In the heading of the questionnaire it is stated that the completion of the questionnaire is voluntary and that students who choose not to complete the questionnaire will not be discriminated against.

To give some structure to the questionnaire, it was decided to focus the questions on the elements of CPPS. There are several questionnaires that test various aspects of CL. Neo (2004) studied students' perception and reaction to CL. Nebesniak (2007) used a questionnaire to investigate students attitudes towards CL, specifically involvement and student confidence. McLeish (2009) used a student questionnaire to determine students' attitudes towards CL and the degree to which CL facilitate student participation in class activities. Morgan (2005) used a questionnaire to determine the use of CL and social integration. The Cooperative Learning Implementation questionnaire (CSLP, 1998) tries to determine why teachers choose to implement (or not implement) CL strategies.

Unfortunately, a suitable questionnaire evaluating student perceptions and the structuring of the five elements of CL in groups of two, could not be found. It was therefore decided to adapt and reformulate questions from the questionnaires mentioned above (CSLP, 1998; McLeish, 2009; Morgan, 2005; Nebesniak, 2007; Neo, 2004) and where necessary, formulate new questions to determine students' perception of CPPS. The questionnaire used before the intervention, contained seventeen statements. In the questionnaire used after the intervention, an eighteenth statement, evaluating perception, was added.

The response to each statement could vary on a Likert scale between “Do not agree at all” (1), to “Agree to a small extent” (2) to “Agree to a large extent” (3) to “Fully agree” (4). Five of the seventeen statements were reverse-phrased to reduce response bias (Field, 2013).

4.6.1.3 Structure of the questionnaire

As mentioned already, the statements were focussed on the elements of CL. Three statements specifically aimed at testing the perception of CPPS, apart from the five elements, were also included.

4.6.1.3.1 Positive interdependence

Positive interdependence is the most important element of CL (Johnson et al., 2008, p. 1:14). The statements are shown in Table 4.2. The statement number (as in the questionnaire) is shown first, thereafter the statement. If the statement was a reformulation of a statement from an existing questionnaire, the number of the statement in the source document and the reference are shown in the right-hand column.

Table 4.2: Positive interdependence

No	Statement	Source
7	During CPPS it was a waste of time to help my team mate.	
8	Both the team members benefitted equally from working together.	Q7, 13 (B. Morgan, 2005)
10	During CPPS my contribution was necessary for the group to be successful.	Q6 (B. Morgan, 2005)
12	CPPS is simply a collection of two individual efforts.	
15	CPPS is detrimental to the better student.	Q6 (CSLP, 1998)

Statement 7 tried to determine to what extent students felt they benefited from helping a team mate – therefore the existence of a situation where everyone benefits. Statement 8 tries to determine whether both members found benefit from cooperation and Statement 10 whether students felt that their contribution made a positive difference. In hindsight, Statement 8 could have been generalized by dropping the word *equally*. Statement 12 attempted to measure the existence of cooperation and Statement 15 yet again whether a situation existed where everyone benefits.

4.6.1.3.2 Individual accountability and personal responsibility

Students often complain about an uneven distribution of workload during group work (Baker & Clark, 2010). It is therefore important to determine whether the workload was evenly distributed and the extent to which students were committed to the team. Three statements were used to evaluate this aspect. These statements are shown in Table 4.3.

Table 4.3: Individual accountability and personal responsibility

No	Statement	Source
1	During CPPS both team members contributed equally towards attaining the group's goal.	Q6 (Neo, 2004); Q2 (P. Morgan, 2000)
9	During CPPS both team members were up to date with the problem we were working on.	Q1 (B. Morgan, 2005)
11	During CPPS I felt a sense of responsibility towards my group.	Q4 (B. Morgan, 2005)

4.6.1.3.3 Promotive interaction

"Positive interdependence tends to result in promotive interaction" (Johnson & Johnson, 2013, p. 89). The statements in Table 4.4 are aimed at evaluating the extent to which students helped each other.

Table 4.4: Promotive interaction

No	Statement	Source
2	I learned more by working with someone compared to working on my own.	Q8 (McLeish, 2009); Q5,12,13 (Neo, 2004); Q2,6 (Nebesniak, 2007); (B. Morgan, 2005)
4	During CPPS I could use my unique abilities to the advantage of the group.	Q4 (Neo, 2004); Q3 (Nebesniak, 2007)
13	During CPPS the two of us helped each other.	

Statement 2 evaluates the benefit the individual found from cooperation. Statement 4 focus on the contribution an individual felt he could make. Statement 13 probes the possible mutual benefit students might have experienced.

4.6.1.3.4 Group work skills

Students must have the necessary social skills to work together. These skills become more important as the group size increases, the complexity of the task increases and the longer the group stays together (Johnson et al., 2008). In this study, students cooperated in groups containing only two members and the group only stayed together for a single tutorial session. The task was also simple as they only had to solve the prescribed problems. It therefore seemed reasonable to assume that most students should possess sufficient social skills to work together. To confirm this assumption, the statements in Table 4.5 evaluate the harmony in the group.

Table 4.5: Harmony in the group

No	Statement	Source
3	Conflict regularly occurred during CPPS.	Q9,11 (Neo, 2004); Q19 (B. Morgan, 2005)
5	During CPPS my team mate listened to my contributions.	Q18 (B. Morgan, 2005)
6	CPPS taught me to cooperate better with other people.	Q7 (Neo, 2004)
14	During CPPS I had enough confidence to ask my team mate questions.	Q4 (Nebesniak, 2007)

Communication is a social skill (Smith et al., 2005). Statements 5 and 14 determine whether the team members possessed the skill to create an atmosphere where members felt at liberty to contribute and felt that they were being listened to. Statement 3 is reverse-phrased and focussed on the existence of a harmonious working relationship in general, and Statement 6 on whether students felt that they developed their social skills during their exposure to CPPS.

4.6.1.3.5 Perception of CPPS

Three statements on the perception of CPPS are shown in Table 4.6.

Table 4.6: Perception of CPPS

No	Statement
16	CPPS helped me to fit in socially.
17	CPPS increased my stress levels.
18	In a next subject, I would like to work in groups of two again.

The goal of Statement 16 and Statement 17 were to confirm to what extent two of the advantages of CL, better relationships between students and ability to cope with stress (Johnson et al., 2008), were realized. Statement 18 was aimed at gauging the overall feeling of students about CPPS and appeared only in the questionnaire given to students after their exposure to CPPS.

4.6.1.4 Data analysis

Two analyses were done on the responses to the questionnaire to determine their perception of CPPS in general and specifically the structuring of the elements of CL.

Firstly, a factor analysis was performed on the students' responses to the questionnaires after the exposure to CPPS and secondly the responses to the statements in the questionnaire before and after exposure to CPPS are compared. An dependent *t*-test was used to determine whether a significant shift took place.

4.6.1.4.1 Factor analysis

The first step in a factor analysis is to determine the correlation between answers to the statements. Two statements will correlate well if the students who agreed (or disagreed) with one statement also agreed (or disagreed) with the second statement. To keep all correlations positive, the score to some statements in the questionnaire had to be adjusted because the statements were reverse-phrased.

Statements correlating well with each other are grouped together. These statements are then studied to determine whether there is a common theme. This common theme is called a factor (Field, 2013). As explained in paragraph 4.6.1.3, specific statements were formulated to evaluate students' perceptions of the structuring of each of the five elements of CL. However, during factor analysis, the statements often group together differently than originally intended. The value of Cronbach alpha and mean inter-term correlation for each factor was calculated. The interpretation of the values are described in paragraph 4.7.2.1. The factor analysis and the loading of statements into factors are discussed in Chapter 5.

4.6.1.4.2 Dependent *t*-test

The questionnaire filled in before the intervention provided a baseline for measuring students' perception of CPPS. The students' responses before and after exposure to CPPS were compared. An dependent *t*-test was performed to identify significant differences between their answers before and after exposure to CPPS.

4.6.2 Academic performance

Two types of analyses were performed on the effect of CPPS on academic performance, a quasi-experiment, and a correlational analysis (over a period of four years) of the effect of the number of tutorials attended on students' academic performance.

4.6.2.1 Quasi-experiment

4.6.2.1.1 Population and sampling

The control group for the quasi-experiment was the students of the classes who took Thermodynamics the year before CPPS was implemented (classes of 2012 at the two universities). The experimental group was the students of the groups where CPPS was implemented during the tutorials (the classes of 2013 at the two universities). CPPS was implemented at all tutorials during the semester and was the only intervention tested. Quantitative data was collected from the whole class of both years.

4.6.2.1.2 Data analysis

The marks obtained by the control group in their first examination opportunity were compared to the marks obtained by the experimental group in their first examination opportunity. The Admission Point Score scale (APS) value for each student was used as covariable to control for the effect of academic ability. The APS score is determined by averaging the results obtained by students in their final school year for all subjects excluding Life Orientation.

An ANCOVA is used to determine whether a significant difference exists between the experimental and control groups of each university.

4.6.2.2 Correlational analysis

4.6.2.2.1 Population and sampling

As CPPS was now implemented each year during Thermodynamics tutorials at University B, data on attendance of CPPS tutorials and academic performance at this university were available for the years 2013, 2014, 2015, and 2016. The records of all students enrolled for Thermodynamics at University B for these years were used to determine the effect of number of tutorials attended on academic performance.

4.6.2.2.2 Data analysis

As attending tutorials at this university was not compulsory, there was a difference in the number of tutorials attended by different students. Therefore, the effect of the number of tutorials attended on academic performance could be investigated. This was done by determining the effect size of the difference in the academic performance of students attending a different number of tutorials.

As it was possible that diligent students would obtain good marks, because they work hard and also attend tutorials because they are diligent, a covariable was identified to control for diligence and intelligence. This covariable consisted of the average of marks obtained in other modules. Suitable modules were identified by correlating the marks obtained in those modules with the marks obtained in Thermodynamics prior to the implementation of CPPS.

4.6.3 The understanding of thermodynamic concepts

A quasi-experiment was used to determine the effect of CPPS on the conceptual understanding of students.

4.6.3.1 Population and sampling

The control group for the quasi-experiment was the students of the classes who took Thermodynamics the year before CPPS was implemented (classes of 2012 at the two universities). The experimental group was the students of the groups where CPPS was implemented during the tutorials (the classes of 2013 at the two universities). This is the same groups as in the quasi-experiment used to determine the effect of CPPS on academic performance (paragraph 4.6.2.1).

4.6.3.2 Compiling the concept test

As mentioned in the discussion of concept tests in Chapter 2, several concept inventories exist (Midkiff et al., 2001; Prince et al., 2013; Streveler et al., 2011). However, they could not be used as is, since each has a different emphasis, or some of their questions were formulated ambiguously. It was therefore decided to compile a new concept test aligned with the course content: properties of pure substances, conservation of energy in closed systems, conservation of energy in open systems, reversible and real systems, and entropy and the second law.

Suitable questions from existing concept tests were used or adapted or new questions formulated as necessary. To make sure that the questionnaire tested the concepts as intended and the questions were clear and unambiguous, the questionnaire was reviewed by an experienced and knowledgeable colleague with several years teaching experience in thermodynamics. Taking his comments into consideration, the questionnaire was adapted. Nine students who had already passed this subject were then asked to complete the second draft questionnaire and note the time they needed to complete the questions. They were also asked to make notes and comment on any aspect of the test. The notes and comments were discussed with the students and the necessary changes made to finalize the questionnaire. The complete test of conceptual understanding is shown in Appendix H.

4.6.3.3 Data acquisition and analysis

The students took the test at the commencement of the classes of the semester following the semester in which they had Thermodynamics to allow enough time to elapse so that they should rely on their understanding of the concepts and not on rote-learned information. The control groups were not exposed to CPPS while the experimental groups were. The same questionnaire was used for the control and experimental groups.

The statistical consultation service of University B analysed the scores to determine whether there was a significant difference between the control group and experimental group of each institution. (The two universities were not compared with each other.) To account for possible differences between two groups of each institution, the average of the final grade obtained by students in Mathematics and Science in their last school year were used as covariable. An ANCOVA is used to determine whether a significant difference exists.

4.7 Trustworthiness of the empirical research

Several measures are employed to ensure that research is trustworthy. The qualitative and quantitative aspects will be discussed separately.

4.7.1 Qualitative research

Creswell (2014b) mentions three facets related to the trustworthiness of qualitative research: qualitative validity, qualitative reliability and qualitative generalization. Shenton (2004) mentions that authors such as Guba prefer to use different terms to distinguish qualitative from quantitative measures. Credibility (in preference to internal validity) asks whether the findings are accurate, whether the researcher’s presentation is a true picture or an accurate reflection of the respondents’ views or the situation they observed. Dependability (in preference to reliability) asks whether approaches followed during the research were reliable, in other words, dependent and stable. In the natural sciences tests are repeated under the same conditions to determine their consistency but in qualitative studies this approach may be problematic due to the changing nature of the phenomena being studied. Despite this fact, qualitative approaches should be described properly to enable an independent party to verify that proper research practices have been followed (Shenton, 2004). Transferability (in preference to generalizability or external validity) is the extent to which the results of a study will be valid in other contexts.

Several steps were taken to ensure the trustworthiness of the qualitative research.

As shown in Figure 4.2, several perspectives were taken into consideration and where possible triangulated, to confirm the validity of the results. As researcher, I was involved in the teaching of Thermodynamics and the supervision of tutorials for many years. I was responsible for the format and execution of all the tutorials and supervised two of the three tutorial groups. I was therefore familiar with the atmosphere in tutorials and the dispensation of students during tutorials – both without and with CPPS. Furthermore, the CPPS procedure was the culmination of four iterations (van Niekerk & Mentz, 2013; van Niekerk et al., 2011) and it was possible to eliminate non-essential or counterproductive measures from the procedure and data acquisition instruments.

The student assistants at University B were all postgraduate students who attended Thermodynamics as undergraduate students. Several had prior experience as assistants. They were therefore well qualified to be trustworthy observers.

My only status at University A was that of a researcher. I was in no position to disadvantage participants for giving a negative or critical opinion. Interviewees in all cases were selected randomly and it was stated in the invitation that cooperation was voluntary. Care was taken during the interviews to put interviewees at ease. The questions used during the interviews and in the questionnaire, were reviewed by an experienced colleague to ensure that the questions were relevant, open-ended, and nonthreatening. An independent party checked the transcriptions and coding of the interviews, questionnaires, and observer reports. The coding of the interviews was re-worked a few times to ensure that there was no drift in the definition and meaning of the codes and I was satisfied that I presented as true a picture as I could of what the interviewees said. All the procedures followed were well-established procedures and are properly described in the relevant paragraphs.

The generalizability of the research is strengthened by the fact that the research was conducted at two different universities. The degree programme presented at both, are internationally accredited which would strengthen the validity at similar institutions. The theoretical framework upon which the procedure is based consists of well-established theories. It should be reasonable to expect that similar results will be obtained in engineering science or even pure science problem-solving tutorials. The reception of CPPS at another university will be dependent on the facilitator's ability to convince students of the merits of CPPS and student's willingness to accept the procedure. The random allocation of partners is rigid and may not be effective if the resolve of the facilitator is not strong enough, or the culture at the university does not support the facilitator in the implementation of the procedure.

4.7.2 Quantitative research

As mentioned already in the introduction to paragraph 4.6, the statistical analysis of all the quantitative data were performed by the statistical consultation service of Institution B by a consultant with a PhD and many years' experience.

4.7.2.1 Likert-scale questionnaire

The same questionnaire was used before and after exposure to CPPS. The first questionnaire tested students' perception of group work up to that point, while the second tested their perception of CPPS – a specific form of group work. The term *group work* in the questionnaire students filled in before exposure to CPPS was replaced by the term *CPPS* in the questionnaire students filled in after exposure to CPPS. Sufficient time had elapsed between answering the two questionnaires that students would not have remembered their responses in the first questionnaire as the first questionnaire was answered during the first meeting and the second at the last tutorial at the end of the semester.

It is common to take the value of Cronbach's alpha (CA) as an indication of internal consistency or reliability. CA gives an indication of the agreement between the answers to the individual statements (making up the factor) and the factor itself. In other words, do the answers to the individual statements have the same agreement-disagreement profile as that of the factor? A value of 0.7-0.8 is usually taken as an indication of sufficient internal consistency (Field, 2013). (The factor analysis of the data is described in paragraph 4.6.1.4.1.)

The mean inter-term correlation is the correlation between the terms in the factor. According to Clarke & Watson (1995) the value should be between 0.15 and 0.55.

4.7.2.2 Quasi-experiment

Some threats to internal validity could not be controlled. As the control and the experimental groups were taught in different calendar years, the examinations they took were different and the prior history of the two groups would have been different. At university A, the Afrikaans group had a new lecturer in 2013. The same lecturer as previously was responsible for the coordination and administration of the course (content, assessments, and tutorials) and lectured the English-speaking experimental group for half a semester. The other half of the course was presented by a new lecturer. The course content and textbook, while not the same at the two universities, were the same for the control and experimental groups at a specific university. At University B, I lectured and supervised the tutorials for both the control and experimental groups. The course content, approach and textbook remained the same.

As described in paragraphs 5.8 and 5.9, in order to compensate for possible cognitive differences between the control and experimental groups, a co-variant (Creswell, 2008) was used in the analysis of the data. The intention was to compare the effect of CPPS on conceptual understanding and academic performance at a specific university and not to compare the two universities with each other.

With regards to external validity, the approach of lectures in the morning with a problem-solving tutorial was (and still is) a common approach at both University A and B in the engineering and science faculties and probably also at these faculties at many other universities. It therefore seems reasonable to assume that the effect of CPPS on both academic performance and conceptual understanding would be the same in modules with a similar approach – where students are expected to solve reasonably well-structured problems with a single correct answer during tutorials – in both engineering and science faculties.

4.8 Administrative procedures

4.8.1 Ethical procedures

I applied for and received clearance from the Ethical Committee of University B to carry out the research. The application contained the motivation for doing the research, a description of how the research will be funded, participants in the research, a consideration of the ethical implications of the research, a description of the methodology, how the data will be analysed, as well as copies of the instruments used during the research. A copy of the letter from the committee granting ethical clearance appears in Appendix A.

I had a meeting with the management and lecturers responsible for presenting the Thermodynamics module at University A and made a presentation, explaining to them the rationale behind the CPPS procedure and the goal and methodology of my research. Subsequently University A contracted me to coordinate, prepare and present the tutorials during the first semester of 2013. At University B, I was already responsible for presenting the introductory thermodynamics course. The research for this study was the part of ongoing efforts to find an alternative teaching-learning strategy for thermodynamics and the research took place with the full support of the head of the department.

All participants (students, assistants, and observers) were informed about the goal of the research, that their participation was voluntary, and that they would not be disadvantaged in any way should they choose not to participate. Details can be found in the appendices containing the questionnaires and email invitations.

Conducting research on your own students has an impact on two aspects: the protection of the participants and the data gathering process (Pool & Reitsma, 2017). There is a power differential between the lecturer and the student and anonymity of participants can most probably not be guaranteed – especially in qualitative research. This may have an impact on the responses provided by students. Also, during data gathering and analysis, a conflict of interest for the researcher may arise between adhering to sound research principles and manipulating the gathering and analysis of the data. However, during interviews, replacing the lecturer as interviewer may have a negative impact on the quality of the data gathering process as the lecturer may be in the best position to react to cues during the interview. If a teaching strategy is being researched, it may also be difficult for students to exercise their right not to participate.

Shirley Comer (2009) identifies the following pitfalls when using students as participant in the lecturer's research: perceived or actual coercion, lack of confidentiality, and the absence of meaningful informed consent She advises against the practice of doing research on your own students. On the other hand Geoffrey E. Mills (2011) states that this type of research has been condoned for many years by ethics committees and stresses the importance of meaningful informed consent.

Pool and Reitsma (2009) found that clear guidelines for this type of research are limited. In spite of that, due diligence require a proper review of the research by a knowledgeable ethics review committee as well as a well-developed sense of ethical conduct by the researcher.

4.9 Intervention

The steps followed during the implementation of CPPS during the tutorials will now be described. Specific reference will be made to the structuring of the elements of CL.

At both universities, there were three conventional lecture sessions in the morning and a single tutorial session one afternoon per week. The procedure was implemented during the tutorial sessions. At both universities, the course was the first introductory course to thermodynamics. Students were introduced to the fundamental concepts and the first and second laws were covered. At University A, thermodynamics cycles were also covered while at University B thermodynamics cycles are covered in another course. Thermodynamic cycles are an application of the fundamental concepts.

4.9.1 Introducing CPPS

From the literature it transpired that students often resist the implementation of CL strategies and that it is necessary to make a conscious effort to obtain their cooperation (Felder, 2007; Oakley, Felder, Brent, & Elhajj, 2004). Therefore, during the first meeting with the students, the three approaches to teaching (individual, competitive and cooperative) and the advantages of CL were discussed (Johnson et al., 2008). It was also emphasized that the ability to work with other people was viewed by prospective employers as an important skill (Collins et al., 2004), hence it was explained to the students how to establish a working relationship with their partners. The procedure they had to follow during the tutorial was described and motivated with reference to the five elements of CL. The students thus knew what to expect from the tutorial. The first step in the procedure when the students entered the tutorial class was group formation.

4.9.2 Forming pairs

Felder et al. (2000) as well as Oakley et al. (2004) recommend that students should not be allowed to form their own groups, because this has a negative effect on positive interdependence and promotive interaction. Therefore, pairs were formed by randomly allocating seats to students. Three different approaches were followed and because group formation is such an important step, each approach will be described.

As attendance was compulsory at University A, we had a good idea of how many students would turn up for the tutorial. As the students entered the lecture hall, two assistants handed each a small piece of paper with the number of the seat where students were supposed to sit. The seat numbers were randomly distributed throughout the lecture hall. The lecture hall was big enough to allow for open seats between students. After a few tutorials, it became apparent that students increasingly ignored the seat number to sit with friends. As the class was filled randomly it was not obvious when a student ignored the seating arrangement and sat with friends. Some students could therefore not sit in their designated seats (because it was already occupied by someone who decided to ignore the arrangement) and had to find another place to sit. That caused the seat allocation system to become ineffective. Because no record was kept of who were supposed to sit where (it would have taken up too much time), it was not possible to check whether students sat at their allocated places.

It was then decided to have students fill the lecture hall from the front, row by row. It was much easier to monitor students filling single rows than it was to monitor students filling the entire lecture hall.

To retain some measure of randomness, the students still received a piece of paper with a seat number upon entering the class. The seats with even numbers in the row were filled first and then the seats with uneven numbers. Thus, two people who entered the class together and took papers right after each other, did not receive seat numbers next to each other. It probably still occurred that individual students ignored the seating arrangement. We did not check whether students sat at their allocated places as it would have taken too much time and effort.

At University B, attendance was not voluntary, and therefore we did not know how many students to expect. It was therefore decided to use the same approach as at University A, and fill the class from the front, row by row, with seat numbers handed out at the door. As discussed in paragraph 4.9.3 students were given a short individual test at the start of the tutorial. At University B, the allocated seat number was indicated on this test. Students received a hard copy of the test as they entered the class, which meant that there was a record of who was supposed to sit where and that made it possible to check whether students sat in their allocated seats. However, this endeavour proved to be impractical, because it took too much time. Individual students could (and did) ignore the seat allocation. Also, students could (and probably did) discuss the test on their way to their seats. This arrangement was abandoned after two tutorials for a much better system.

A laptop computer with a student card reader was used to allocate seats. As students entered the class, they swiped their student cards and were allocated a seat number. This made it easy to check that students sat in their allocated places because we had an electronic record on a spreadsheet. Students who did not sit in their allocated places did not receive any credit for that tutorial. Once the students realised this, they accepted the arrangement and sat in their allocated seats. Only once the students were seated, individual tests were handed out.

4.9.3 Individual test

To encourage individual students to accept individual accountability for their own preparation, students wrote an individual test. The test was printed on a single A4-sheet of paper, lasted 10 to 15 minutes and covered the lecture content of the previous week. The tests were taken in, discussed with the class, and marked by the assistants.

4.9.4 Social skills training

In line with the recommendation that students need to be taught teamwork skills, a different teamwork skill was discussed before each problem-solving session commenced. In this way students could practice a new teamwork skill each week.

The topics discussed included getting organized in the group; extroversion, introversion, shyness and working together; how to handle differences of opinion, and communication (learning to listen, learning to speak). In order to enable students to reflect on their own implementation of these skills, skills discussed during previous tutorials, were reviewed.

4.9.5 Solving problems together

For the problem-solving process, students formed pairs according to the seating arrangement. It was easy to see who had to work together as there was an even number of students in a row. The seats were allocated with open seats between pairs to create space for textbooks, notes, and calculators. To promote cooperation, each pair received a single hard copy containing the tutorial problems that they had to solve.

Positive interdependence is often structured by assigning specific roles to students (Johnson et al., 2008). Because of the large number of students in class, it was not possible to assign roles and ensure that students adhere to those roles. The approach was therefore rather to create conditions that would have promoted positive interdependence and encouraged students to rely on each other.

Students sat next to each other to create an environment conducive to interdependence as it is convenient to cooperate and communicate with the person next to you. To encourage students to share resources and divide tasks (means interdependence), and share their ideas on how to approach the problems, the problems were made challenging and limited time was available for the students to complete the problems. Tasks that could be divided between team members included: looking up values in the tables; doing calculations on the pocket calculator, writing down values and calculations, and finding information in the textbook.

According to the social interdependence theory, positive interdependence will result in students helping each other (Johnson & Johnson, 2013). To furthermore create an atmosphere conducive to face-to-face promotive interaction, the pair was given only one hard copy of the problem sheet, and students were encouraged to divide tasks, share resources and assist one another. Groups were also monitored: groups where one individual did all or most of the work, or where individuals obviously worked independently, were engaged in a friendly yet firm manner and urged to work together.

Assistance was provided and questions answered in such a way as to encourage student-centred learning and structure promotive interaction. By raising their hands, a group could indicate that they required assistance from the lecturer or one of the assistants.

Students who left their partners and approached the assistant or lecturer individually for help, were accompanied back to their partners. Assistance was given by probing questions and not by providing answers. Responses were expected from both team members.

If the questions indicated that several groups struggled with the same issue, I addressed the whole class. Typically, the strategy for the specific problem was described on the board without solving the problem itself, which, yet again, created an opportunity for intra-group discussion.

4.9.6 Providing feedback

At University A, once a pair completed the problems, they handed in hand-written copy with their calculations and were free to go. The questions, key equations and answers for the test and tutorial problems were made available on the course website immediately after the tutorial. The hand-written copies with the calculations and answers were marked by the assistants.

At University B, the process was more comprehensive: Each pair submitted their student numbers and answers by mobile phone on a dedicated website during the tutorial. When the facilitator was satisfied that students had sufficient time to complete the problems, they were warned that the website was going to be closed. After the website was closed, the solutions to the problems were discussed and explained on the board. This gave the groups the opportunity to grade their own efforts and reflect on their performance and interaction.

As backup for the website, students filled in their names, answers, and final marks on the hard copy of the problem sheet and handed it in as they left. The tutorial problems and the final answers were made available on the course website. The student assistant downloaded and graded the answers submitted by the students. By comparing the student detail submitted on the website with the record of allocated seats, it was relatively easy to check whether students sat at their allocated places.

At both universities, the scores obtained for the individual test before the tutorial as well as the problems completed in pairs were accumulated and the final average score contributed towards the students' semester mark. At University A, the accumulated average contributed 15%

towards the participation mark. At University A, 15% is the figure used in other subjects as well. At University B, the accumulated average was a 5%-bonus added to the participation mark. The reason for making it a bonus mark is to eliminate the administration of keeping record of students who had valid reasons for not being able to attend the tutorial.

The reason for the small contribution towards the participation mark is twofold. In the first place (except for the individual test) ample help was available for the completion of the tutorial problems. The students could consult each other, the assistants, and the lecturer.

It was therefore easy to obtain high marks. Secondly, we wanted the primary reason students attended the tutorial to be the benefit they gained from learning together and the activity of solving problems together. However, awarding some points is one way of holding students individually accountable and encouraging them to prepare for the tutorials.

4.10 Summary

In this chapter, the methodology followed to gather the empirical data to answer research subquestions 2, 3, 4 and 5 was discussed. A pragmatic approach was used and data was collected using a convergent parallel mixed methods design to answer research subquestions 2 and 3, and quantitative methods to gather data to answers research subquestions 4 and 5.

In the parallel mixed methods design, the quantitative measurement was a Likert-scale questionnaire. The qualitative measurements used were student interviews, student assistant questionnaires with six open-ended questions, observer reports, two open-ended questions in the student questionnaire, and the researcher's journal. The students in the experimental group were asked to complete the questionnaire before and after their exposure to CPPS.

The methods used in the purely quantitative part of the study was a quasi-experiment to determine the effect of CPPS on academic performance and conceptual understanding, and a correlational analysis to determine the effect of the number of tutorials attended on academic performance. At University A as well as University B, the control groups for the quasi-experiment were the 2012-students who were not exposed to CPPS, and the experimental groups were the classes of 2013, where CPPS was implemented during tutorials. As CPPS is now implemented every year since 2013 during Thermodynamics tutorials, data on tutorial attendance and academic performance were available for 2013, 2014 2015 and 2016. This data was used in the correlational analysis to determine the effect of the number of tutorials attended on academic performance.

The steps followed during the implementation of CPPS, consisted of the random allocation of partners, a short test covering the work students had to prepare for the tutorial, a discussion of group work skills and then handing out of the problems students had to solve together. At completion of the problems, students submitted or handed in their answers. At University A, the solution was posed on the course website and the answers marked by the assistants while at University B, the solutions to the problems were discussed in class immediately after students submitted their answers.

CHAPTER 5
RESULTS AND DISCUSSION

5.1 Introduction

In the previous chapter the research design and methodology were described. In this chapter, the focus is on analysing the empirical data. In the next chapter, the results of these analyses are combined to reach conclusions regarding the main research question and subquestions.

The chapter is organized according to the analysis of the data from each data gathering instrument. The interviews are analysed first.

5.2 Student interviews

The student interviews were one of the data gathering instruments used to determine the extent to which students experienced the structuring of the five elements of CL (research subquestion 2) and gain an understanding of the perception of the students of CPPS (research subquestion 3). The analysis of the data related to each question is discussed separately.

5.2.1 Structuring of the five elements of CL

The interview questions (paragraph 4.5.1.2) were general in nature and probed the students' experience of the CPPS procedure. The elements of CL are described in literature and were therefore used as a-priori themes in the analysis (paragraph 4.5.1.3). During the analysis, it was found that some quotations could be coded using concepts already described in literature. The rest of the codes were derived from the text.

A diagrammatic presentation of the complex structure of the themes and codes for both universities are shown in Figure 5.1 and discussed in more detail afterwards. The codes shown in bold were derived from the text of the interview transcriptions.

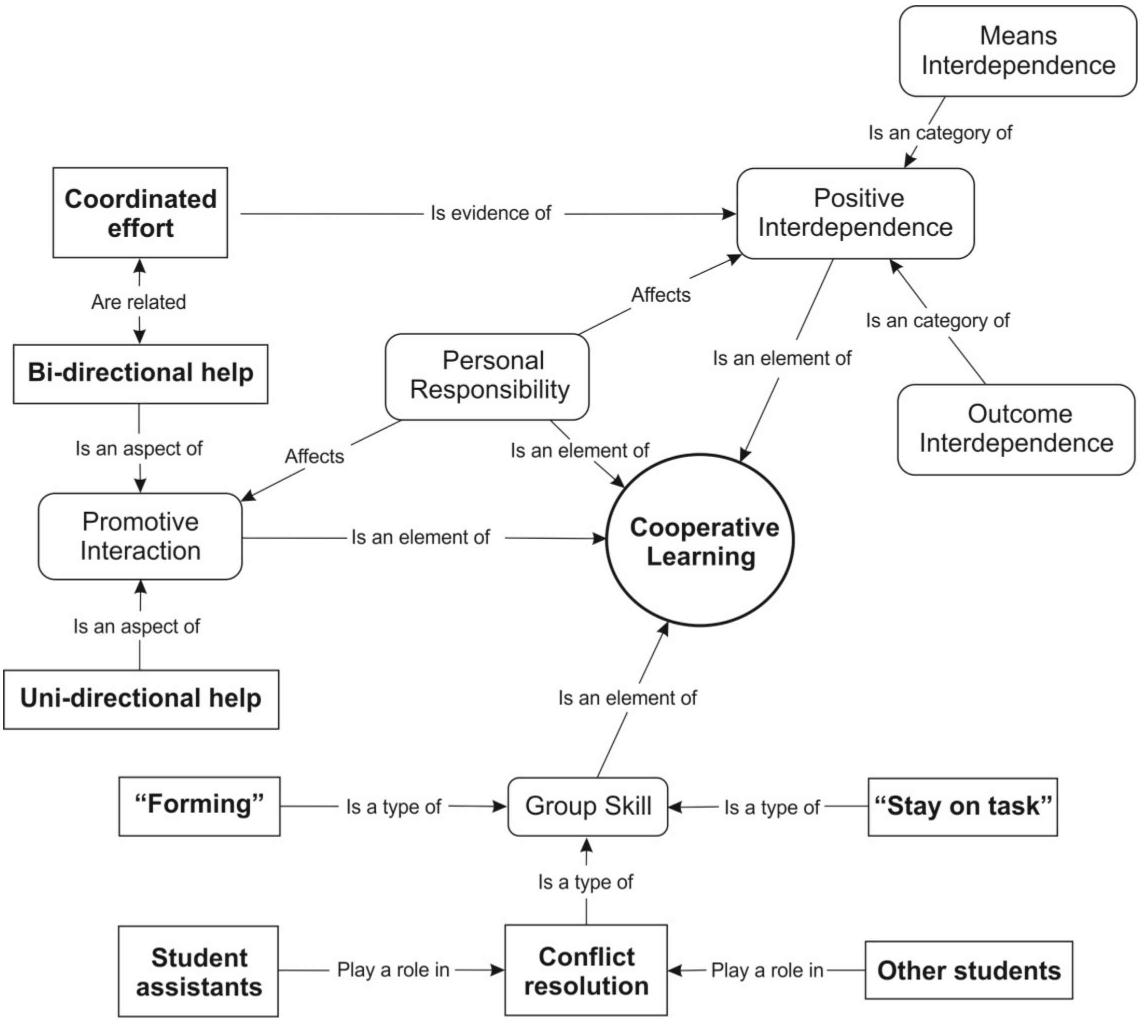

Figure 5.1: The structure of the themes and codes used in the analysis for the elements of CL

The procedures for implementing CPPS at the two universities differed in smaller detail, because allowance had to be made for established procedures at each university. Therefore, the interviews conducted at the two universities are analyzed and discussed separately. The first element considered is positive interdependence.

5.2.1.1 Positive interdependence

As discussed in paragraph 3.3.1.1, positive interdependence exists when students have the perception that they need to rely on each other and coordinate their efforts to succeed.

5.2.1.1.1 University A

Several interviewees mentioned how they coordinated their efforts: *Group work helped solve the problem because each one gives a bit of input and that led to the eventual solution.* [A4]

And: *So when you share ideas you come up with a better solution in the end. [A11] And: … then I would see certain things that they wouldn't and they would see certain things I wouldn't …* [A5]. The fact that students had limited time to solve the problem also promoted positive interdependence. One interviewee said: *Because people would see OK, this tutorial is a bit long and two minds are better than one. So the approach works fine because now you are working together as a team.* [A11]

One of the two main categories of positive interdependence, outcome interdependence was structured in the procedure by expecting the two students to hand in one set of calculations, which was graded by the student assistants. Both students were awarded this mark. Johnson and Johnson (2013) set a condition for outcome interdependence: While achieving the group's goal, individual team members should also achieve their own individual goals. Several students mentioned that cooperation led to better individual understanding: S*o you help each other and at the end of the tutorial you get the concept much better than before* [A12], and: T*hen we will have [to] sort of battle through it, [and] you figure it out. That was very beneficial to me.* [A2]

There is also ample evidence of the second main category of positive interdependence, namely means interdependence. As described in paragraph 4.9, students were encouraged to share resources (such as the textbook and calculator) and divide tasks (such as writing, calculating, looking up values in the tables). There is evidence that students followed this advice: *When I worked with the other guys, we decided between ourselves who is going to write ... one writes, one do the quick calculations, both read the problem, that type of thing. [A9] And: The textbook is like in the middle and whoever gets it first, does the tables. [A6].* Because of the size of the class, the sharing of resources and division of tasks could not be controlled nor enforced and it was left to the group to decide. *We always changed, then he writes, then I write. [A9]*

As described in paragraph 4.9, conditions were created that made it advantageous for students to rely on each other and coordinate their efforts. The goal of these conditions (as well as the structuring of means and outcome interdependence) was to strengthen the perception of students that they must rely on each other and coordinate their efforts. However, positive interdependence was also dependent on the extent that both students decided to take advantage of the opportunity to rely on, and coordinate their efforts. The disadvantages of not relying on each other and not coordinating their efforts during a tutorial were limited to that specific tutorial. The result was that the strength of positive interdependence varied. A few instances were reported where it seems the feeling of positive interdependence was weak or even absent. A student once found that her partner *would think very fast and I would be writing and then my train of thought wouldn't follow hers.* [A5] (In the next tutorial she made sure that the other student did the writing!)

Another student said that, *If you were with someone who knows the work better, they would say, I know what to do* [A2] and he could only tag along. Asked how often he was left behind he said: *It was about three times that I had to tag along.* (There were thirteen tutorials.) An interviewee mentioned his partner talking on his cell-phone. *It happened once to me. He was not on his phone the whole time, but like the first half of the tut[orial] he was.* [A6]. If the lecturer and assistant were kept busy answering questions of other students, such lack of cooperation could easily go unnoticed in a large class.

Despite the instances where the feeling of positive interdependence was weak or even absent, it seems that in general students realized that *two heads are better than one* [A9], and felt the need, accepted the responsibility, and experienced the advantages of coordinating their efforts.

5.2.1.1.2 University B

One aspect of positive interdependence, outcome interdependence, was structured by expecting the two students to provide a single answer to each question. As explained in paragraph 4.9.6 a website was created where each pair submitted their answer to each problem using their cell phones. The group's answers were marked and they both received the same mark. For backup, they handed in the hard copy of the problem sheet with the answers written on the back.

The existence of positive interdependence at University B was evident from the description of several interviewees on how they coordinated their efforts. *You get to share ideas on how to do calculations. People see things differently and people have different starting points in terms of ideas.* [B2] It helped this student to "argue" the problem and "hear it out loud" – both his own and his partner's verbalization. And: *I suggested equations that I knew would work, for which I knew the variables and then the other guy said yes, he agrees or no, he has other equations. [B4]*

The physical environment promoted the second category of positive interdependence: means interdependence. The two students in the pair sat next to each other (environmental interdependence) and several interviewees mentioned that they shared resources: *Steam tables we did share*. *Otherwise there are too much papers and notes on the desk, so we use one textbook and one of the steam tables. [B6]* And: *I had the textbook and my friend the study notes. So I would search the steam tables and he would look for the equations. [B8]*

Attendance of the tutorials at this university was voluntary that seemed to lead to better cooperation between students. An interviewee said: *Students who attended wanted to work [B9].*

In contrast to University A, no mention was made by any interviewee of students not cooperating with their partners. This seems to imply that students who attended the tutorials generally accepted the responsibility of making the team "work". This included cooperating with and depending on their partners.

From the comments of students at both universities it seems positive interdependence was dependent on two variables. Firstly, positive interdependence was structured into the procedure. This structuring included outcome and means interdependence and creating an environment that promoted cooperation. Secondly, positive interdependence was also dependent on the extent to which students accepted the responsibility to make a success of working together.

According to the social interdependence theory, the type of interdependence determines how individuals interact. Promotive interaction should result from positive interdependence (Johnson & Johnson, 2013). As discussed in paragraph 3.3.1.2, promotive interaction is characterized by individuals helping each other to achieve the group goal. Evidence of promotive interaction at the two universities is now discussed.

5.2.1.2 Promotive interaction

More than two thirds of the interviewees mentioned – often more than once during the interview – how they valued and found benefit from being with somebody else in a specific way: that their understanding complemented each other.

The remarks of interviewees regarding complementary understanding of the students at the two universities often augment each other, making a more comprehensive understanding of the concept possible. Therefore, the universities are not discussed separately and quotations from interviewees from both universities are used to illustrate aspects in this paragraph.

5.2.1.2.1 Complementary understanding

The concept of *complementary understanding* emerged from the data and comprises four aspects as shown in Figure 5.2 and is discussed in more detail afterwards.

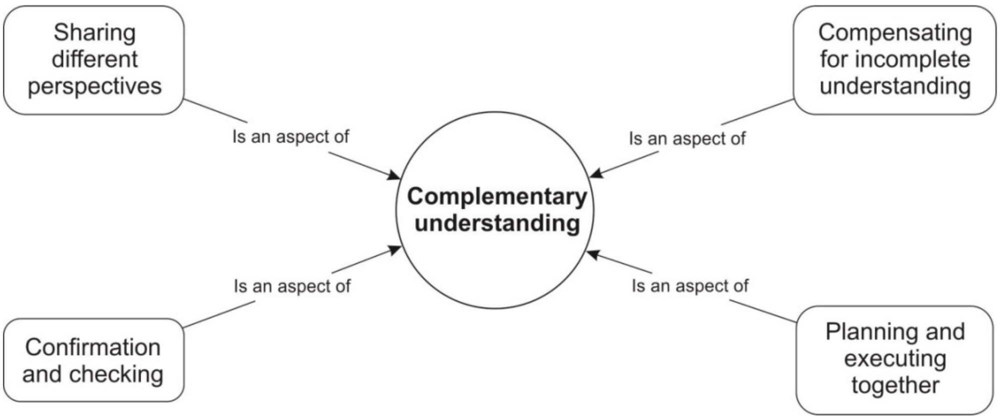

Figure 5.2: Complementary understanding

- Sharing different perspectives

Several students described how they as pair shared their own individual understanding with each other: *And if you are sitting with somebody else you do not normally sit with, then they would have a different outlook on that problem so when you share ideas, you come up with a better solution in the end. So, just that outside perspective of somebody else helps to solve the problem. [A11]* And: *Cooperating in groups of two worked for me, because different people have different perspectives on a problem.* [B8] And: *We first read the problem in silence and then we went through it together. Yes, just to say this is what I see and this is what the other person sees. That is how we approached it.* [B4]

- Compensating for incomplete understanding

When students provided mutual support, they both benefitted: *When you get into a tutorial and you find someone who understand some of the work and you also contribute, so you help each other and at the end of the tutorial you get the concept much better than before.* [A12] And: *I think I make them slow down and look at certain things and then I would see certain things that they wouldn't and they would see certain things I wouldn't.* [A5] And: *What often happens is you get stuck or someone gets stuck and then the friend next to you can often help you. Especially with me, that helped me a lot.* [B3]

- Planning and executing together

Sitting next to another student made it easier for students to discuss the problem and plan a problem-solution strategy before solving the problem: *First, we would read the question silently, like each read it on his own so that we both can understand the question.*

Then we would read it together – one would read out loud and then we would talk about what was given in the question and what we can use to solve the question and how we are going to go about solving it and then we put it to paper. [A11] And: *We will first understand the problem together, discuss it and then do it.* [A9] And: *We read the problem in silence and then I would ask him or he would ask me what he thought of the problem, how we should approach it. [B6]*

- Confirmation and checking

It seems that when solving the problem several students preferred (presumably after discussing the problem) to write down and solve their own equations while continually checking with their partners: *Generally I preferred it if we both did everything because I like it if we can compare answers like: Do you also get 30?* [B1]. And: *[We] would do it together, try and work it out together and double check each other's answers.* [A10] That enabled them to identify errors in their understanding and execution: *If we did not get the same answer, I would ask him 'What have you done?' And then: 'Oh! I see what you have done here!' That helped me*. [B1] And: *It is those small things that really helped me, for instance if I used the wrong value in an equation.* [B9]

Several students also mentioned that one student would do the writing while the other would check his or her reasoning: *The one person will try first and then the other person will look what the first person has done and then they will see where they have gone wrong or they will get another idea.* [A3] And: *It often happened that you maybe cannot write down the mass balance and then the other guy will perhaps mention a small thing that will make you decide okay let us try it. [B3]*

The interaction between the students was also characterized by other aspects.

5.2.1.2.2 Aspects of giving and receiving help

Attendance of tutorials at University A was compulsory, but not at University B and that could have influenced the character of the interaction between students. The two universities are therefore discussed separately.

- University A

Generally, students seemed willing to help each other: *All the people I worked with, was reasonably helpful.* [A7] And: *See, you get intelligent people who are very willing to teach you what they know … it is obviously fantastic, if you get someone who understands the work ... who is willing to communicate this with you … it is amazing.* [A7]

Several students at University A mentioned the fact that it took time to give and receive help. When they were finished, they handed in their calculations and were free to go. Thus, the student doing the explaining, apart from the willingness to explain, must also be willing to spend extra time: *It also depends on the bright guy's personality. If he wants to help you, or if he wants just to finish the tut[orial] and leave.* [A2] And: *I have been seated next to people where they have no understanding of the tut[orial], then in order to work with them ... is a bit awkward because you have to explain to them as well, because you can't just do your own thing. So then it gets a bit awkward and it takes a bit longer to finish.* [A11] It is possible that the reason this interviewee decided to help his partner was the "responsibility forces" created by a perception of positive interdependence as mentioned by Johnson and Johnson (2013, p. 105).

It also happened that there was a breakdown in interaction when there was a big difference between the two students: *People complain that when they sit with someone who is very intelligent or very … not so intelligent, then they have to do all the work or the other [intelligent] guy carry on and do all the work without him.* [A7]

When the difference between students was small enough, both benefitted: *If you are level, then it is beneficial both ways.* [A2] And: *It so happened that we were more or less on the same level and that was fantastic.* [A7]

- University B

At this university, promotive interaction seemed to be more on an equal footing. Only one interviewee mentioned a big difference in preparedness and ability between her and her partner: *With the first tutorial the guy who sat next to me only heard that day that he could take Thermodynamics, so he knew nothing about it. I had to show him every, every, everything.* [B1].

From the interviews at this university it was clear that students were willing – even eager – to share their ideas and discuss possible approaches to the problem with their partners. One student called it *a constructive thinking process.* [B8].

To summarize, evidently students benefited from working with a partner, as their understanding complemented each other in different ways. This complementary understanding and helping behavior could take two forms: (a) bi-directional help, where synergy was created between the two students and both found mutual benefit and (b) uni-directional help, where one student helped and explained to the other.

5.2.1.3 Personal responsibility and individual accountability

In the following paragraph, the interviews are analysed to determine students' feeling of responsibility, especially the impact of environmental factors.

5.2.1.3.1 University A

To encourage students to come prepared to the tutorial, they wrote a short individual test before the tutorial problems were handed out. Several interviewees mention that they prepared for the test: *I know beforehand I have to look over and understand the work because we are writing first.* [A11] And: *It eventually taught me that I have to page through the chapter the previous day.* [A13]

Possibly because of a strong feeling of responsibility due to a strong perception of positive inter-dependence, one student went to great lengths to prepare: *Working in little groups caused me a lot of stress. I spent almost the whole weekend preparing for Thermodynamics in order not to be a liability to the other student.* [A3] Another one was more relaxed: *You wouldn't really want to come unprepared to the tutorial because you'd feel bad that you are not pulling your weight.* [A9]

Working with a stranger does not seem to make a huge difference to their preparation. When asked if he prepared better because he would be working with a stranger and not with a friend, one student said: *No, I do not think so. It is the same for both.* [A8] And: *No, [my preparation would be the same] because I do not like to let another person down* [A7]

Although they may not have prepared better, it seems working with a stranger during problem solving made students put in more effort: *If you work with someone you do not know, you will immediately try and prove yourself, prove that you can do this work.* [A4] And: I*f you do not know the person, you will try and do your bit.* [A7]

Working with strangers also meant students focussed on the work: *Also, it is much more focused on the work if you're are working with a stranger. You've got nothing to get social about.* [A2] And: *If you know the guy, then you are going to talk about other things.* [A4]

5.2.1.3.2 University B

At University B, the environmental factors were slightly different. This difference in environmental factors seems to have influenced the students' feeling of responsibility.

As mentioned in Chapter 4, at this university students were awarded a maximum of only 5%-bonus points for the tutorials. It seems that this shifted the motivation of the students more towards the learning benefits obtained from attending the tutorials than the credits that could be earned: *Most of the people who attend, actually wants to work, so I think that voluntary attendance, 5% bonus marks is a good thing because it keeps the guys who do not want to work away.* [B1] And: *Everybody I worked with were there to learn and find out more.* [B6]

Even though it seems the students attending the tutorials were committed to learn, the fact that the extra credits obtained were small meant that some students easily put other priorities first. This group also wrote a Mathematics class test on the morning of the tutorial*: I wouldn't say thermodynamics came second, I would say the tutorial came second. Cause it's only 5% right?* [B2] And: *I think because it is a bonus 5% many people wrote off the tutorial if they became busy. Because it is only a bonus while in the other subject you will actually lose marks.* [B8]

Working with strangers encouraged some students to put in more effort, both in preparation and during the tutorial: *I think I will prepare better if I work with someone I do not know. The person I usually work with is one of those workacholic types. I know myself, I would have wanted to sponge on him. So I think for me, I will prepare better if I work with someone I do not know.* [B1] And: *Yes, you are out of your comfort zone and I think [working with a stranger] helps you to perform. If I work with a friend, if I cannot do something, it does not matter as much and you do not put in as much effort.* [B5]

At both universities, the attitude of students with regards to working with strangers varied over a wide spectrum and it was difficult to discern a pattern from the interviews by itself. The perception of students about working with strangers is explored in detail in paragraph 5.3.1, where a framework for student attitudes towards working with strangers is proposed.

5.2.1.4 Group skills

Even though groups consisted of only two people and they stayed together for only one tutorial period, students still needed to be able to form a team, cooperate with a stranger and resolve differences of opinion. The two universities are again discussed separately.

5.2.1.4.1 University A

It seemed that students generally worked well together at University A and that an atmosphere conducive to learning was created.

Several students valued the fact that they got to meet new people: *I enjoyed that … because you meet new people … you are acquaintances. When you see them you can go: Hi!* [A6] And: *The general feel in the class has actually changed a bit, I must admit … we know more people, more people know each other … it is just far more comfortable with those guys, everyone knows each other so … It definitely changed the feel in the classroom as well.* [A10]

One student felt the random allocation of partners was a gamble and expected that there will be instances where he would be paired with someone he would not get along with, but it did not happen. He said he was pleasantly surprised, and added: *I think in the end everyone sort of is decent people.* [A2] Another student said: *We fit in with each other most because we don't know each other and you want to get along with people.* [A6] There were exceptions. One of the interviewees remarked: *Some days you end up with people with little knowledge or incompatible personalities.* [A9]

Students who got stuck during problem solving, or had a difference in opinion on how to solve a problem, made use of several options to resolve the difference. Student assistants played an important role: *If we got stuck we raised our hand[s] and asked an assistant.* [A7] The assistants also helped to resolve conflict: *But when there is a discrepancy or something like a conflict, then you can't solve it until you ask a demmie [assistant].* [A6] Several students mentioned that they asked other students (not their partners): *Sometimes we would ask the people sitting across from us, which was also nice when we got stuck.* [A5] One interviewee and his partner could not agree on which approach to follow during interpolation. They decided that each one will do it his own way and then to compare answers. After comparing answers, the partner agreed that the interviewee was right. The interviewee commented: *Sometimes it is better if he does it his own way and [then we] compare whether it leads us to the same answer.* [A12]

There is also evidence that students displayed another interpersonal skill, namely "stay on task" (Johnson et al., 2008, p. 7:1). A female student said: *It is initially a bit awkward to meet the person. Once you start working, you focus on the work.* [A3]

As the semester progressed, students' social skills developed. Several students mentioned that they got used to cooperating with an unknown person, *I think it was quite enjoyable. Initially it was a bit different, a bit of an adjustment, but the last few weeks one got used to it.* [A8] And: *I didn't feel that awkwardness after the first few times.* [A11]

5.2.1.4.2 University B

At this university, it also appears that students possessed sufficient group work skills to cooperate effectively and even make friends.

Students mentioned that they got to know more people. A interviewee remarked: *It actually enables you to make friends much easier. I have made two friends from it. Also it broadens up your mind set of other people in terms of stereotype.* [B2] And: *On a personal, social level I think it is a very good thing because I have met five guys that I did not know studied with me and we talk a lot and you get to know your fellow students also.* [B6]

Students got used to working with strangers: *Initially when we heard how it is going to work, it was a bit strange but later we got used to it and it improves you people skills.* [B6] And*: I liked it, because we got to know each other. It does help, you get comfortable.* [B5] One student described his approach when meeting his partner: *Just hear what is his name, where does he stay, get comfortable with each other.* And: *You are more focussed on the work. With friends, one does the work and the other talk.* [B6]

One student said once or twice he worked with someone with whom he could not establish a good working relationship: *We socialize more than they do and then it is difficult to connect with them, because they know what is going on [with the work] but because their social skills are not so good, they cannot always explain what they know and how to do it on a level that I will understand.* [B4]

In general students felt positive about working with strangers: *It was good to work together in groups with people you did not know.* [B5] And, *For me personally, I do not have a problem working with people, so for me it was a positive experience*. [B8]

The lecturer and student assistants also played a role in resolving differences of opinion: *When he thinks he is right and I think I am right then it is very simple, we raise our hands and ask the lecturer: Is this right or that? And so you sort it out.* [B3] And: *The student assistant helped a lot, because often, when you do not understand, then you call an assistant. [B7]*

5.2.1.5 Group processing

As discussed in paragraph 4.9.4, when a new group work skill was discussed, group work skills introduced during previous tutorials were reviewed. As a form of in-group processing, students were encouraged to show their excitement when they solved a problem and give recognition for a contribution by a partner.

5.2.1.5.1 University A

During the first class meeting when CPPS is introduced to the students, a group skill “forming” (Johnson et al., 2008, p. 7:5) is discussed.

The students are advised to get organised after introducing themselves to each other. They should decide who is going to do the writing, whose tables and textbook they are going to use, who is going to do the calculations, and so forth. It seems students generally followed this advice. One student said: *When I worked with the other guys, we decided between ourselves who is going to write ... one writes, one do the quick calculations, both read the problem, that type of thing.* [A9] And: *It was quick to communicate with the guy or girl and get together.* [A8] And: *This is a guy that you do not know but after talking a bit, we got a bit more comfortable with each other.* [A1]

Some students reflected on the interaction during group work. One interviewee could not convince his partner about a certain procedure. Only after they both did the calculation individually; his partner was convinced. He concludes, *Sometimes it is better if he does it his own way and [then we] compare [afterwards] whether it leads us to same answer.* [A12]

5.2.1.5.2 University B

At University B, students were given a chance to reflect on their performance as a group in solving the problems. After the students submitted their answers on the website, the solutions to the problems were discussed on the board and the students could check their solutions and mark their own answers. When asked what contributed the most to her understanding of the problems during the tutorial, one student said: *I would say the discussion afterwards, because sometimes you do not really understand the problem that you have done [during the tutorial]. When I had the most 'AHA!' moments was when we went through the problems afterwards.* [B1] And, *I liked it if we went through the memorandum afterwards. Then you understand OK, this is where I went wrong, or where my reasoning was off.* [B3]

One interviewee reflected on the interaction with his partners and said: *You have to be patient in terms of responding and questioning. You have to know when to ask a question and when to respond and how to respond. That's what I have learned.* [B2]

This concludes the discussion of students' experience of the structuring of the elements of CL during the tutorials (research subquestion 2). The student interviews were also analyzed to help answer the second research question related to the students' perception of CPPS (research subquestion 3).

5.2.2 Students' perceptions of CPPS

All themes and codes were derived from the text. As can be expected, a specific quotation could be linked to more than one research question. Therefore, some quotations used in paragraph 5.2.1 are used again.

5.2.2.1 Perception of the procedure

Firstly, the students' perception of CPPS as procedure will be discussed. This will be followed by the discussion of the perceptions of specific aspects of the procedure. The two universities are discussed separately.

5.2.2.1.1 University A

At University A, perceptions of the procedure varied. One student was very positive: [*Apart from the initial problems with seat allocation] everything else was absolutely perfect. Really, that was pretty … I mean, I really enjoyed it.* [A10] Most students were positive but more reserved: *I think that it might be quite a good idea.* [A5] Two of the thirteen interviewees did not like the procedure and would have preferred to work alone. One said: *It put me under a lot of stress and I did not enjoy Mondays at all.* [A3]

5.2.2.1.2 University B

At University B, attendance was voluntary. Therefore, those who attended were positive about the procedure: *I actually liked it very, very much.* [B3] And: *It helped me a lot. So I feel it was a good thing.* [B4] The students who did not like the procedure stayed away: *Two of my friends, after the second tutorial, said 'This is nonsense!' or something like that, and then stayed away.* [B9]

At both universities, several interviewees mentioned that they like CPPS because of the assurance it brings to have somebody at your side. When you are alone, even a small mistake can steer you in the wrong direction, or prevent you from finding a solution, but not when you are with a peer: *It is more just the concept of two brains that work together … things, small detail that you have missed the other person will tell you about.* [A9] And: *If you work alone, what will happen if you get stuck? Who is going to help you?* [B7] And: *It is those small things that really helped me, for instance if I exchanged something in the formula. [B9]*

A challenge seems less daunting if you are a team: *Because people would see OK, this tutorial is a bit long and two minds are better than one. So the approach works fine because now you are working together as a team.* [A11]

During the interviews, perceptions about specific aspects emerged.

5.2.2.2 Group formation

Some aspects of the CPPS procedure did not leave the student any choice. For instance, all groups consisted of only two people and students were not allowed to form their own groups. The fact that students could not choose their partners was often mentioned during the interviews at both universities. It was evident that many students resented this fact. However, there were also students who admitted that working with strangers encouraged them to prepare better and helped them to focus on the work.

5.2.2.2.1 University A

At University A, attendance of the tutorials was compulsory. Students received a random seat number upon entering the class. It was not possible to ensure or check that students sat at their allocated seats.

Random seat allocation was met with strong resistance from some students. One student confessed to ignoring the seat allocation system: *I cheated a bit and each time worked with a friend.* [A9] After initially ignoring the seat allocation one group of students eventually accepted the arrangement: *We are a group of friends who always sit together. Initially it was us who sat together in the tutorial but then we decided to cooperate.* [A9] Some students got used to the arrangement: *Initially, I think it was a bit annoying for the most people but you get used to it as you go along.* [A13] There were students who accepted the arrangement: *After a while, I got used to the system – working with somebody new. I just accepted, OK that is the system, I have to do it.* [A11] And: *Yes, I tried sticking to the numbers.* [A3]

There are two aspects related to group formation: working with friends and working with strangers.

- Working with friends

It seems most of the interviewees feel more comfortable working with a friend: *It is much nicer to work with a friend. You are comfortable with him. [A1]* It is not always clear what is meant by "comfortable".

One said that it is easier to ask a friend: *If you do know [the other person] it is easier to ask.* [A2] And: Y*ou know the person, you feel comfortable, you feel at liberty to ask questions and reason a bit about what is right and what is not right.* [A7] And: *So I mean with a friend I would assume that you would be more open, you just give an opinion, no matter what.* [A11]

- Working with strangers

However, the same students seem to realize that working with a stranger also have advantages. If you work with a stranger *you've got nothing to get social about.* [A2] Also, you will make more of an effort when working with a stranger: *If you do not know the person, you are going to try and do your bit.* [A7]

A few admitted that it is better to work with strangers even though it may be more uncomfortable: *I am not going to say I enjoyed it, but it is for the best. Because you work more and you generally do get more work done.* [A11] A student at University B shared this sentiment: *I think they do not like working with strangers because then they must put something in. I experienced [in other subjects] that working with an intelligent student allows you to copy his work. It is not difficult then.* [B5]

A few interviewees enjoyed working with a stranger: *To a certain extent I enjoyed challenging myself to get to know the other person and to be put in a somewhat uncomfortable situation.* [A7] Another interviewee said he enjoyed working with strangers: *because then you meet new people* .[A6]

Two of the thirteen interviewees at University A were adamant that they preferred working alone: *I learn more if I work on my own. If I encounter a problem, I will ask people who can explain better to me. [A3]*

5.2.2.2.2 University B

At University B, a laptop computer with a card reader was used to randomly allocate seats to students. Students swiped their student cards and was allocated a seat. It was therefore possible to check afterwards that students sat at their allocated places. Students who did not stick to that seat number did not receive any credit and it seems students generally accepted the arrangement: *For me personally, I do not have a problem working with people, so for me it was a positive experience.* [B8] And: *I think it was good to work in groups with people you do not know.* [B5]. Students who did not like the CPPS procedure simply stayed away. *Two of my friends, after the second tutorial, said 'This is nonsense!' or something like that, and then stayed away.* [B9]

Interviewees recognized the advantages of working with strangers. In other modules, where they could work with friends, one interviewee mentioned how they copied from a strong student: *We have one friend that is very intelligent and he does the work and everybody copies from him.* [B3] And: *I learn better and is more focussed to do the work [when I work with a stranger]. Otherwise you are going to sponge on the other guy if you do not want to work. You also do not want him to sponge on you. So you are a bit more focussed.* [B6]

With regards to group formation and the random allocation of partners, it seems that, while many students would have preferred to work with friends, they realized the advantages of working with strangers and became accustomed to working with strangers as the semester progressed.

5.2.2.3 Individual test at the beginning

To encourage students to come prepared to the tutorial and keep them personally responsible, the first activity after students were allocated their seats, was writing a small individual test. The standard of the test was supposed to be reasonable for a student who attended the classes, understood the lectures, and briefly revised the work before the tutorial.

5.2.2.3.1 University A

At University A, the general practice in tutorials in other subjects was that students do the tutorial problems first and wrote an individual test after they completed the tutorial problems. Doing the tutorial problems first, gave students the opportunity to familiarize themselves with the content and concepts before having to take the individual test.

Most interviewees at University A resented the fact that the individual test was written before doing the problems. Although they did study in preparation for the test, some still felt ill-prepared and made remarks such as: *I would [like to work in groups of two again] but definitely the test thing would have to be changed. Rather at the end or the next week, so we do the work in the tutorial and then write the test*. [A5] And: *So now that I have to write the test first, I don't have that full understanding of the work and then after the tutorial I realise, OK this is how you do it!* [A11] Another interviewee was satisfied with the standard of the individual test: *For [someone] attending classes and staying up to date, the [standard] of the test is right.* [A9]

There were another difference between the CPPS tutorials and tutorials in other modules. In some other modules at University A, the tutorial problems are made available a day or two before the tutorial. With CPPS they only received the problems after writing the individual test and had to prepare all the work covered since the previous tutorial.

Some students felt this made it difficult to prepare: *The fact that we cannot get the tutorial [problems] beforehand makes it very difficult to prepare.* [A13] And: *Getting tested on work that you [are] not sure [of] what is going to be in the test. You arrive there and it could be anything that you have learned over the last two weeks. [A2]*

It seems that the fact that CPPS tutorials were different to the other tutorials may have contributed to negative perceptions of CPPS at University A: *Because the system is different to every other tutorial, they are not used to it.* [A11] *And*: *There should be a standard. If all the tutorials are being done this way, then do all the tutorials this way. Otherwise, for every subject you will have to have a different kind of study method. [A6]*

5.2.2.3.2 University B

At University B, the lecturers of different modules were free to each follow their own approach during tutorials. This seemed to render students more susceptible to different approaches and no resentment about the individual test was voiced during the interviews with the students of University B.

This concludes the analysis of the student interviews, which gave a view from “inside”. The assistant questionnaires and observer reports provided a perspective from the “outside”. The assistant questionnaires are discussed first.

5.3 Student assistant questionnaire

The student assistants at University A were asked to answer six open-ended questions (paragraph 4.5.2) to give them the opportunity to share their observations of the cooperation and interaction between the students as well as allow them to give their own opinion of the success and shortcomings of CPPS. The student assistants were all postgraduate students who did this module as part of their undergraduate study. One of the assistants was a PhD student with several years’ experience as student assistant in Thermodynamics. Several others also had previous experience as student assistants. The themes and codes were derived from the text. A quotation of a student assistant is indicated with an “SA” (Student Assistant, University A).

5.3.1 Random allocation of partners

The aspect that perhaps elicited the most reaction from students was the fact that they could not choose their own partners and therefore usually had to work with strangers.

Different aspects related to working with strangers were raised during the interviews with the students and discussed in paragraph 5.2.2.2. Interviewees mentioned that while some students liked meeting and working with strangers, others preferred working with friends while some preferred to work alone, but it was difficult to discern an underlying pattern explaining these different preferences.

The answers of the student assistants provided a catalyst for the formulation of a framework which may help understanding student preferences with regards to group formation. However, the answers of the student assistants are not sufficient to adequately illustrate the scope and reach of the framework. To strengthen and provide substance to the framework, quotations from the student assistants' responses as well as from the transcriptions of the student interviews are used.

Without purporting to cover all possibilities it seems the students can be divided into five categories, which seems to have played a determining role in shaping their attitude towards CPPS:

- **The conscientious student.** The first category comprised conscientious students who were part of a group of like-minded students. These students knew each other and cooperated effectively during tutorials in other modules (traditional tutorials) where they could choose their own partners. A student assistant wrote: *The typical student for which the traditional tutorial works well, has a group of friends (or one friend), also dedicated to their studies with whom he cooperates well. Such students would dislike CPPS.* [SA6] And: *Many of the students already have friends with whom they sit during class and with whom they study. They know each other's study methods and are comfortable working together. I do not think they like CPPS a lot.* [SA7]

  The student interviews confirmed that there were students who fell in this category. During the interviews, one of the students said: *We are a group of friends who always sit together. Initially we ignored the seat allocation system and sat together but later we cooperated.* [A8] Another student said: *I have cheated the system and worked with my one friend all the time.* [A9]

- **The passenger or free loader.** These students feed off stronger, better-prepared students. Freeloading during traditional tutorials seemed to be common. A student assistant wrote: *[In traditional tutorials] a group of students would consist of between 2 and up to 5 or 6 [students] and some would do the work with others just copying [from them].* [SA2] This point is confirmed by a student who was repeating the module.

He described the situation during tutorials the previous year as well as his own attitude*: You are not really bothered much about the work and sort of rely on one guy. He was passing down [the answers]. We are talking about ten guys copying from one guy. So you knew absolutely nothing [of the work at the end of the tutorial.]* [A10]

During CPPS, freeloading would be difficult because there are only two in the group. One assistant wrote: *Since the good student wanted to get good marks the dodger was frowned upon.* [SA10] Another wrote: *It seems that generally both partners contributed something: The students generally divided the work equally.* [SA1] And: *From answering the questions the students asked, it appeared that often one student would be more knowledgeable than the other, however they seemed to be putting in the same work.* [SA4]

Students inclined toward free-loading would be reluctant to admit that CPPS was a good experience *because CPPS requires more effort [of them].* [SA6]

- **The outsider.** This student, although he or she may be hard-working and well prepared, is not part of a group. Reasons for being an outsider can be that he or she *is more reserved.* [SA6] Students repeating a module, or those who have a part-time job, often tend to be more on their own. An assistant wrote: *CPPS provides students who are more on their own with a wonderful opportunity to cooperate with someone else. There was a large measure of cooperation and goodwill in the groups.* [SA6] And: *Often there was one shy person in a pair, however since its only two people it makes it easier for people to loosen up and work with other people.* [SA1] And: *Well, they seemed to be talking a lot to each other so there was in a way 'forced socializing'. Having a common ground (focus on the tutorial) oils the wheels of social interaction.* [SA10] Fraser (1993) also found that an important benefit of working in groups, is that it helped students who are not part of a group in the class, to form relationships.

  It is possible that "outsiders" would also be positive about CPPS. During the interviews one student said: *It is OK to work with another person. There is nothing wrong with it. I didn't feel that awkwardness after the first few times.* [A11] Another interviewee said: *I enjoyed it to a certain extent to challenge myself to get to know the other person better and to be put in a somewhat uncomfortable situation.* [A7]

- **The extrovert.** This category was not mentioned by the student assistants but it was clear from the student interviews that some students derived energy from their interaction with others: *Often what would happen is that two pairs would start talking. Like two weeks ago the same thing happened, my partner and the other pair had absolutely no idea what was* *going on in the chapter, I think it was chapter nine and I had to explain to them the procedures what we were actually doing with the problem, where they were coming short,*

I found that really worked well. [A10] And: *The one tutorial that I wasn't very prepared for the other person also wasn't very prepared for it so we find a way through it and learned lots of things.* [A5] It was clear that both these interviewees enjoyed social interaction. Both were positive about CPPS: *Especially when we were forced to go to new people I liked that … we know more people, more people know each other so there is this general … I do not know, it is just far more comfortable ... everyone knows each other.* [A10]

- **The strong introvert or shy student.** This category was also not mentioned by the student assistants but it was clear that there were students who wanted to work on their own despite being exposed to CPPS: *I think I would have learned more on my own. Perhaps it is only me, I study better when I work on my own. If I stuggle, I will ask someone who can explain to me.* [A3] And: *I do not like working with someone else. I would have preferred to work on my own.* [A4]

5.3.2 Other perceptions of the student assistants

One student assistant felt that CPPS *would work better in modules where you apply the CPPS system to [get students to] do projects/reports/assignments together.* [SA1] The other nine assistants were positive about CPPS. A few were very impressed: *In my opinion a fantastic idea* [SA9]. And: *I think CPPS is excellent*. [SA5] The rest was more reserved: *I think it is a fresh system which creates a better learning environment.* [SA6] They note several positive aspects:

- **Students are more focused:** *This was the quietest, most focused tutorial I have ever been in, both as a student and an assistant. All the students worked hard and focused on the task as opposed to the general noise and talking/socializing that normally goes on in a tutorial*. [SA5] And: *The students work well together and because they may not be familiar with their partner the social aspect is reduced and they focus more on getting the work done. [*SA9]

  However, some mentioned the need to enforce the random allocation of partners: *The quality of the tutorials degenerated as students continued to sit in their friendship groups and correspondingly spent less time actually working and more time chatting.* [SA5] And: *I like CPPS. However, there are a few problems, including the fact that the students don't sit in their appropriate groups. I feel CPPS should be tried again, but enforcing the random pairs.* [SA4]

- **Students helped each other:** *Often there was one 'bright' student helping the 'less bright' student, which is beneficial for the 'less bright' student. [SA1] And: I also noticed that when one of the students understood something, he readily explained it to his partner.* [SA8].

- **Sometimes students obtained synergy:** *I found that when two students who were obviously good students were paired they challenged each other and had very good and in depth questions for the demmies [assistants], often beyond the scope of the work. I also found that when two 'poor' students were paired that their combined output was often quite significantly improved and that they seemed to spend lots of time figuring things out and in so doing gained a lot from each tutorial.* [SA5] And: *There were the ideal cases where two students would put their heads together and reason about the problem and solve it.* [SA6].

- **There were social benefits:** *The students seemed more comfortable reaching out to demmies and I think CPPS gives the students some feeling of comradeship.* [SA3] And: *They therefore must have understood the thermodynamics much better and that in my opinion contributed to the more cheerful atmosphere in the class.* [SA10]

These observations of the student assistants correspond with the remarks made by several interviewees that CPPS provided an effective learning environment.

At University B two observers were asked to attend a tutorial and share their observations.

5.4 Observer reports

The observer reports were analysed for the structuring of the five elements of CL.

5.4.1 Positive interdependence

Both observers noticed that students shared resources: *As a rule, students used and shared textbooks, notes, and electronic sources such as cell phones/iPads. In a few cases it seemed as if students used their own resources and shared calculations afterwards.* [OB] And: *Positive [resource and role] interdependence was good with students sharing tasks, outputs and resources.* [OA]

It also seemed that students considered their partners as a resource and that they coordinated their efforts: *An explanation by the lecturer of the problem-solution strategy or the solution to the problems [after students submitted their answers] was followed by intensive discussion between the members of the group, explaining the work to each other or trying to get clarity of what has been said.* [OB]

5.4.2 Promotive interaction

One observer noted: *There were several groups where one member explained the solution to the other until the other member understood.* [OB] And: *Everybody cooperated actively. Only a few were on their own mission. [OA]*

5.4.3 Individual accountability

Generally, it seems both students accepted their responsibility towards the group and contributed: *It seems that most groups used the inputs from both members and that the group was not dominated by one person* [OB] One observer was satisfied with the structuring of individual accountability: *Individual accountability was good with the individual test at the beginning and that both students were responsible for the final answer.* [OA]

5.4.4 Group skills

It seems the students possessed sufficient group work skills: *The students' group work skills are really good ... most worked amazingly well together* [OA] And: *Generally their body language showed that students were comfortable working together* ... *they seem to listen to each other.* [OB]

Except for group processing, which was not mentioned, both observers seemed to be satisfied with the structuring of the elements of CL into the procedure.

The fourth qualitative method was the researcher's memoirs.

5.5 Researcher's perc**eptions**

5.5.1 Background

CPPS was implemented during the first semester of 2013 at University A and again in the second semester of 2013 at University B. A journal was kept during the implementation at both universities. Due to the positive results of CPPS, it has been implemented at University B ever since. CPPS was therefore implemented four times at University B, in 2013, 2014, 2105 and 2016 and once at University A in 2013. Due to the repeated implementation of CPPS, it was possible to form a clear picture of the different aspects of CPPS. The journals, perceptions and experiences were combined and described in the researcher's memoirs (Appendix D). Specific aspects of CPPS as it emerges from the memoirs are now discussed.

5.5.2 The creation of a learning environment

For me, one of the important advantages of CPPS is that it takes a huge teaching load off the shoulders of the instructor. I remember: During one of the first CPPS tutorials, shortly after the students received their problem set, I wanted to tell them to quiet down and start working. Then I realized that they were working – that the noise of conversation is exactly what was supposed to happen. I realized that they were explaining to each other and searching for solutions together. I was used to be the one who did the talking and the explaining while expecting the students to be quiet and pay attention to what I was saying, or solve problems on their own in silence. It was a huge relief to realize that it was not the case anymore, that it was not necessary for me to explain often trivial detail to individual students. Fraser (1993) also found that students working in groups solved many problems in the group which allowed the lecturer to focus on more difficult problems that students could not solve in the group. Furthermore, I realized that much more learning was most probably taking place than would have been the case if I was the only one talking.

Also, when I had to attend to a question from the two students in a group, it was easier to explain to the two of them. Often one student was quicker to understand and I could leave it to the quicker student to explain to the other student so that I could attend to a question from another pair. If it became evident that several groups did not understand a concept, I explained the concept to the whole class on the board. It was reassuring to know that students could explain to each other if necessary.

5.5.3 Cooperation between students

Upon receiving the problem set, students almost involuntary turned towards each other, read, and discussed the problem. It was obvious that they worked together, one doing the calculations, the other looking up values in the tables. The initial seat allocation for writing the individual test was such that there was an open seat between students, but generally students moved to sit next to each other when they received the problems, to be able to read from the single problem sheet handed to each pair. In isolated cases, the seat between them remained open. When I noticed two students not cooperating I would address the issue.

5.5.4 Random seat allocation

As mentioned, students were not allowed to choose their own partners. A proper, robust seat allocation system was found to be vital.

As students entered the class at University A, they were handed a piece of paper with a seat number.

There was no record of which student was supposed to sit where and in so doing check to ensure that students sat at their allocated places. It was left to the facilitator to try to ensure that students sat in their allocated seats. Some students made their dissatisfaction and irritation with not being able to sit with friends palpable, and it took hard-nosed determination from the facilitator to enforce the arrangement and admonish students who obviously did not sit in their allocated seats. That had a detrimental effect on the atmosphere in class. Despite our best efforts, and motivating the random allocation of partners, there were always students who did not sit at their allocated seats. This practise had a snowball effect. For every student not sitting at his or her allocated seat, two students were affected: the student who was supposed to sit at the seat now occupied by the “cheater” and the student now sitting alone because the student who was supposed to sit with him, was sitting with a friend.

I did not want to play the enforcing role again and was fortunate to find someone at University B who was able to adapt a program running on a laptop which allowed students to swipe their student cards and be allocated a seat number. The seat allocation was random and recorded in a spread sheet. It was now possible to determine whether students sat at their allocated places. Students who did not sit at their allocated places did not receive any credit and students quickly accepted the arrangement. It was a relief to get rid of my policing role and have a water-tight system. Using the PC to allocate the seats and especially being able to check that students sat at their allocated seats was a key aspect in the successful implementation of CPPS for me. If I was not able to ensure that students sat at their allocated places, I do not think I would have continued with the implementation of CPPS after 2013. Printing and cutting the seat numbers at University B also proved tedious.

5.5.5 Grading of calculations and individual tests

At University A, student assistants were assigned to each module to assist during tutorials and grade the tutorial tests and solutions handed in by the students. There were four assistants for the Afrikaans group and four for the English group. Two assistants did the grading.

Because two students handed in one answer set, the grading load on the student assistants was reduced by 50%. However, returning the graded copies to the students posed several problems as there were two students and only one copy. Which of the two students should collect the graded copy? How should the graded copies be arranged? Alphabetically according the first author? How can the other student get a copy of their solution set? It often took two weeks for the problems to be graded and made available. By that time students often lost interest. The table where the graded tutorials were placed became cluttered as all students did not collect their tutorials.

In line with the instructions of the course coordinator, only the final answer and the main points of the solution strategy were made available on the student website. Several students complained that this was insufficient and that they preferred more detailed solutions.

At University B, students submitted their student numbers and the answers to the tutorial problems on a website using their cell phones. The website was then closed and the solutions to the tutorial problems discussed with the students. This gave students the opportunity to ask questions and check their own calculations. Students filled in their names and the answers to the questions on the problem sheet and handed it in as backup. Their answers submitted on the website were downloaded as an Excel spread sheet and graded by the assistant.

The procedure at University B is preferred. It provides immediate feedback to the students, it provides them with an opportunity to reflect on their cooperation, and it dramatically reduces the time required for marking and administration.

5.5.6 Compulsory vs voluntary attendance

At University A attendance of tutorials was compulsory for all students taking Thermodynamics for the first time. At University B attendance was voluntary.

One likely advantage of voluntary attendance is that students who do attend will be more committed. A disadvantage is that students may decide not to attend just because they do not like CPPS for trivial reasons; and in doing so miss valuable learning opportunities.

The last qualitative instrument was the two open-ended questions in the student questionnaire.

5.6 Analysis of two open-ended questions in the student questionnaire

Before and after their exposure to CPPS, students were asked to complete a questionnaire with several Likert-scale questions. The questionnaire also contained two open-ended questions:

- If relevant, please provide example(s) of something that you have learned because of group work / CPPS that you would not have learned if you were working alone.
- If relevant, give an example of a problem experienced by a group / CPPS group to which you belonged, and explain how the problem was solved (if at all).

The students generally gave only one answer for each question. Therefore, these answers most probably reflected the dominant or first thought that came to mind when reading the question.

The answers to the questions were analyzed using data-driven codes to determine the students' perception of CPPS. These codes were grouped under themes. Because of the large number of answers, it was possible to deduct some indication of the strength of a code or theme from the number of answers correlating with that code or theme. Having students complete the questionnaire before and after exposure to CPPS, presented the opportunity to determine whether a shift has taken place by comparing the number and percentage of answers correlating with a specific theme before exposure to CPPS – with the number and percentage of answers correlating to the same (or similar theme) after exposure to CPPS.

However, some caution is necessary. It must be kept in mind that the analysis of the two open ended questions is a qualitative analysis. Students did not always provide an answer to the question, but used the opportunity to voice their opinion about group work, or about the CPPS procedure, or an aspect they felt strongly about at that moment. One student answering the question about what he has learned, decided to voice his opinion about the process instead and wrote: *I find that I gain a greater understanding of the work when completing the test after the tutorial. This gives us more opportunity to learn and ask questions regarding the work before writing the test.* [A159] Some students provided more than one answer.

Still, the number of answers correlating with a specific theme could be determined with reasonable accuracy, therefore the number and the percentages of answers relating to specific themes and codes are reported. Numbers and percentages are also used for reasons of linguistic convenience. It is easier to use numbers and percentages rather than phrases like "almost half the students" or "well over two-thirds".

In the following section, the experience and perception of CPPS at the two universities are discussed separately.

5.6.1 University A

To determine their experience and perception of CPPS the answers supplied by the students after exposure to CPPS are analyzed first.

5.6.1.1 First question, after exposure to CPPS

The first question was, "If relevant, please provide example(s) of something that you have learned because of CPPS that you would not have learned if you were working alone." Of the two hundred and fifty-seven questionnaires received back, hundred and twenty-nine students provided an answer to the first question. Of these, five students provided two answers. Eight answers were not relevant. A total of hundred and twenty-six answers were therefore included in the analysis (129 + 5 – 8 = 126). The themes and number of answers associated with each theme are shown in Table 5.1.

Table 5.1: Themes for answers to the first question after exposure to CPPS, UniversityA

THEME	Number of answers	%
CPPS facilitated learning	86	68
My group work skills improved	16	13
Negative perceptions and experiences	15	12
Other positive perceptions and experiences	9	7
TOTAL	126	100

- **CPPS facilitated learning.** More than two thirds of the students (86 out of 126 = 68%) indicated that CPPS facilitated learning. These answers could be grouped according to six codes as shown in Figure 5.3.

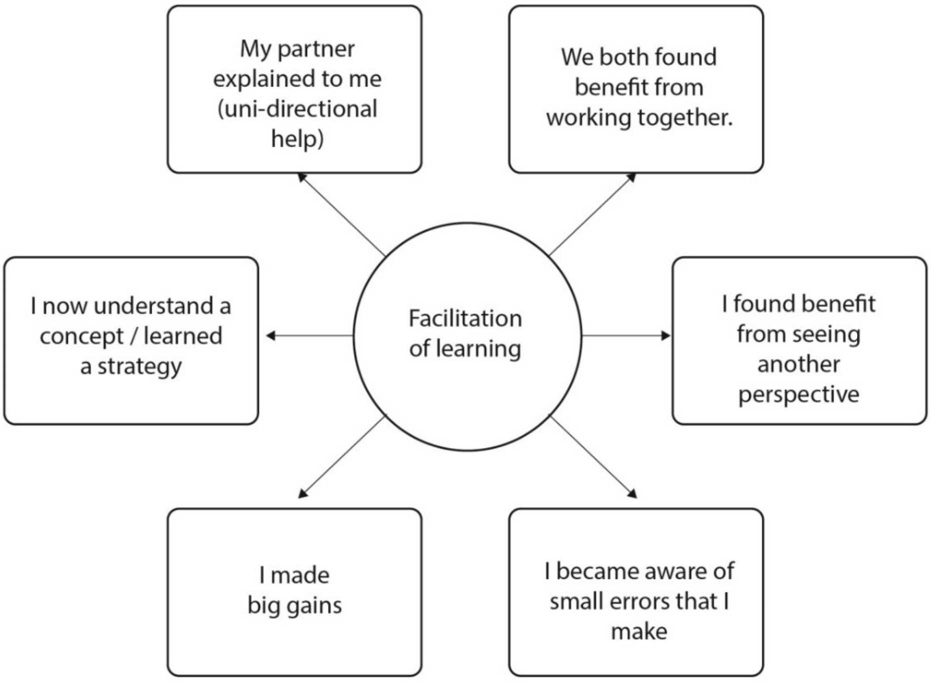

Figure 5.3: Codes associated with the theme "CPPS facilitated learning"

Several students felt that both team members found benefit from working together, exchanging ideas and sharing their individual understanding: *Teammates question each other's methods, teaching the other [student] their point of view. It usually resulted in a* *better understanding*. [A160] And: *Many a time my team mate knew things I didn't know and vice versa. I learned things from him and he learned new things from me.* [A169] Several said that they found benefit from seeing another perspective: *Multiple perspectives work towards a better understanding of the work.[A200]* And: *It helped to see some problems from another viewpoint and solve it in another way.* [A15]

Several students said that teamwork helped them to rectify a small misunderstanding or detect small errors: *[Working together] helps iron out small problems you had and maybe weren't even aware of.* [A178] And: *Several small traps that the other person understood how to solve, I now also understand.* [A122] Several said that teamwork helped them make bigger gains: *I had many gaps in my knowledge that would have remained if I were not able to be told about them.* [A183] And: *I learned a number of approaches and problem-solving methods.* [A176] Finally, several students mention that working together helped them learn a strategy or understand a concept: *I learned how to interpolate and how to draw diagrams from partners and how to present work properly.* [A148] Several specifically mention their team mate: *Sometimes I did not understand a concept properly, and my partner could help me improve my understanding.* [A1] And: *I didn't know all of the work and my group member helped me.* [A158]

- **Social gains.** Thirteen percent of the answers (16 of 126 = 13%) could be grouped under a theme "social gains". Most answers grouped under this theme relate to the improvement of group work skills: *I learned to co-operate better with people and also learned to have more trust in others' knowledge.* [A207] And: *[I have learned) to work with people with different personalities.* [A39] One student laid a different emphasis: *It was comforting knowing we both struggled with the same questions. It showed we were on par with the work.* [A131]

- **Positive perceptions.** Under the theme "positive perceptions" one student said: *I concentrate harder when put under pressure that comes through working in a group I am unfamiliar with.* [A150] Another said: *I found it kept me up to date whereas last year, when I did the course, I fell behind very easily and hence [I am] repeating it this year.* [A198]

- ***Negative perceptions.*** Twelve percent of the answers reflected negative perceptions. Several did not like the fact that they could not choose their own partners: *You cooperate better with people that you know and if you do not know the person it is easier to work alone.* [A51] Others did not like group work: *People work at different tempos and the group can only work as fast as the slowest member.* [A114]

  Problems and negative perceptions also emerge from the answers given by students to the second question which is discussed in the following paragraph.

5.6.1.2 Second question, after exposure to CPPS

One hundred and fifteen students at University A provided an answer to the second question, "If relevant, give an example of a problem experienced by a CPPS group you belonged to and explain how the problem was solved (if at all)." Ten answers were not relevant. The answers were coded with data driven codes and grouped under themes. The themes and the number of answers corresponding to each theme are given in Table 5.2 and then discussed.

Table 5.2: Themes for answers to the second question after exposure to CPPS, University A

THEME	Number of answers	%
Unequal contribution by partners	29	28
Ineffective cooperation	22	21
Negative perceptions	23	22
Solved a tutorial problem	21	20
No problem	10	10
TOTAL	105	100

- **Unequal contribution by partners** Twenty eight percent (29 of 105 = 28%) of the students mention an unequal work load distribution as a problem. Sometimes it seems to be an isolated event: *During one CPPS group, my partner contributed absolutely nothing. He never said a word or even introduced himself when he sat down. I don't think he could communicate in English. I ended up doing the tutorial alone.* [A209] And: *I once had a partner who knew nothing and I did the whole tutorial as he didn't go to class in a month.* [A169] Some students said that they experienced the problem of unequal contribution more than once: *I often had to carry my partner through the tutorial, it wasn't always solved.* [A135] And: *[My] teammate often didn't know the work so I ended up doing most of the work.* [A129] Some formulated the problem as a general comment: *If one student is not up to date with the work, then he/she cannot really contribute.* [A121] A few mentioned an attempt to solve the problem of unequal contribution: *Sometimes it felt as if I did all the work. It was solved by giving my partner something to do even if it was only doing calculations on the pocket calculator.* [A79]

- **Ineffective cooperation.** Approximately a fifth of the students (22 of 105 = 21%) said they could not successfully cooperate with their partner. Several reasons are given.

  (i) Uncooperative partner: *Partner doesn't really co-operate and wants to work on her own not as a team.* [A203] (ii) Domineering partner*: The other guy only trusted his own skills,* *whether it was right or wrong. The problem was not solved.* [A65] (iii) Disagreement: *Me and my group member disagreed on the solution to the problem, we wrote down both solutions.* [A177] (iv) Poor communication: *The other members sometimes communicated poorly. It was solved by asking intelligent questions related to the work.* [A85] It seems that most of the students referred to specific incidences and that unsuccessful cooperation was not a common experience for these students.

- **Negative perceptions.** Twenty-two percent (23 of 105 = 22%) of the students' answers reflected a negative perception about the procedure. Several students in this group did not like the fact that they could not choose their partner and had to work with a stranger: *I think it helps a lot to work in pairs but the fact that we cannot work with partners of our choice makes no sense to me. I work far better with someone I know as I am more comfortable to argue/discuss/ask questions with someone I know.* [A249] And: *You feel embarrassed to ask a stupid question to someone you just met.* [A192] Some would have preferred to work alone: *I think group work doesn't work at all and at least, if you cannot phase it out, please make people pair themselves [rather] than forced pairing.* [A216] And: *I find that I could have done better if I was working alone in a quieter environment.* [A241]

  There were also students who complained about other aspects of the procedure. One said: *The test at the beginning of the tutorial is an irritation.* [A3] Another wrote: *Give us the tutorial before we write the test, or at least some review questions, guidelines of what to go through, etc…*[A250]

- **Solved a difficult tutorial problem.** Twenty percent (21 of 105 = 20%) of the students said that the problem they experienced was a difficult tutorial problem that they could solve. Approximately a half of these students could solve the problem through cooperation: *We did not know where to start with the problem. But as soon as we started to reason about it, it became easier to solve.* [A60] And: *My team mate and I had different approaches to solving a problem. This was resolved by a discussion on which method would be easiest and most practical way to solving the problem.* [A203] The other half asked an assistant: *We disagreed on how to solve a certain problem and we ended up asking a demmie [assistant] to help us.* [A180] And: *Neither of us knew what to do but then a demmie [assistant] helped us.* [A46]

- **No problems.** Ten percent of the respondents said that they did not experience any problems. They made comments such as: *No specific problems.* [A150] And: *Did not really experience any problems.* [A63]

While several students reported problems with regards to cooperation, many used words such as “once”, “during one tutorial” and “some students”, which seems to indicate that these negative experiences were isolated events and that students generally cooperated effectively.

5.6.1.3 Comparing answers in the questionnaires filled in before and after exposure to CPPS, University A

The answers to the open-ended questions in the questionnaire before exposure to CPPS gave an indication of students’ experience and perception of group work up to that point in their study. Asking students to answer essentially the same two questions, before and after exposure to CPPS, presents the opportunity to see whether CPPS brought about a change in students’ perception of group work. The only difference between the two questions is that the questionnaire filled in after exposure to CPPS referred specifically to CPPS while the questionnaire filled in before exposure to CPPS referred to group work.

5.6.1.3.1 First question, before exposure to CPPS

In Table 5.3, the themes in the answers in response to the first question, “If relevant, please provide example(s) of something that you have learned because of group work that you would not have learned if you were working alone”, are shown. Of the two hundred and three questionnaires received back, hundred and fifty-nine students answered the question. Seven students gave two answers which bring the total to hundred and sixty-six. Five answers were not applicable. Hundred and sixty-one answers were included in the analysis.

Table 5.3: Themes for answers to first question before exposure to CPPS, University A

THEME	Number of answers	%
Group work facilitated learning	89	55
Group work skills improved	57	35
Negative perceptions and experiences	15	9
TOTAL	161	100

The answers of fifty five percent (89 of 161 = 55%) of the students indicated that group work (before exposure to CPPS) facilitated their learning. This compares to the 68% of students in Table 5.1, who said that CPPS facilitated their learning. Another 7% of students in Table 5.1 mentioned various positive learning experiences associated with CPPS. This means that three of four responses (68% + 7% = 75%) indicated that students experienced CPPS as an environment where learning takes place. This substantially more than the 55% in Table 5.3 who felt that group work (before exposure to CPPS) facilitated learning.

Thirty five percent of students (57 of 161 = 35%) said that group work (before exposure to CPPS) improved their group work skills while only 13% (Table 5.1) of students indicated that they learned group work skills during CPPS.

The fact that students generally only provided one answer to the open-ended question means that an *increase* in the numeric value of the percentage of answers associated with one theme would necessarily lead to a *decrease* in the numeric value of the percentages that could be allocated to other themes. Therefore, as the number of students who perceived CPPS as a learning experience increased from 55% to 68%, the number of students whose answers (after exposure to CPPS) could be grouped under other themes decreased – such as an improvement in group work skills. A comparison between the percentages before and after exposure to CPPS about group work skills, may therefore not be valid.

Nine percent of the students mention negative perceptions related to group work. One said: *I have learned that I do not work well with others and get frustrated from working in groups.* [A82] To determine whether CPPS changed their perception of group work for the better, their answers in the questionnaire filled after exposure to CPPS were checked. Unfortunately, they did not make any comments related to group work and therefore no conclusions could be drawn.

5.6.1.3.2 Second question before exposure to CPPS

In Table 5.4 the themes for the answers in response to the question "If relevant give an example of a problem experienced by a group you belonged to and explain how the problem was solved (if at all)", are shown. From the two hundred and three questionnaires received back, one hundred and forty students provided answers of which four answers were not applicable. Students provided only one answer.

Table 5.4: Themes for answers to second question before exposure to CPPS, University A

THEME	Number of answers	%
Unequal contribution: Not solved	35	25
Unequal contribution: Addressed	33	25
Negative perceptions and experiences	39	29
Solved problem by cooperation	26	19
Diverse positive	3	2
TOTAL	136	100

Twenty five percent (35 of 136 = 25%) of students indicated that an unequal contribution by team mates is a problem they experienced during group work, a problem that was not solved. Some said it is a common occurrence: *There was always one member who just went along for a free ride, put in no effort at all. The matter never got solved.* [A92] Some students seem to have a specific incident in mind: *Most of the work was dumped on me. The problem was not solved.* [A128] This percentage is almost the same as the 28% (Table 5.2) of students who indicated that an unequal contribution is a problem during CPPS.

Another 25% of the students said they experienced the problem of unequal contribution, but tried to address it: *People were not contributing equally and those members were addressed politely.* [A182] One student suggests a strategy to address such problems: *There is always someone that doesn't do their part properly or even doesn't do anything at all. One must be strict but also friendly to get them to work.* [A75] Often the strategies they applied to solve the problem, does not promote learning: *The task required very specialist skills. It seemed like some members were useless, but we set these members up to do administration.* [A130] And: *Members of the group were not contributing to the tasks. This was solved by telling them it would be left in their hands to present the report.* [A103] Some only suggested ways how to deal with the problem in future: *Sometimes there is someone in a group who does not put in 100% which leaves problems. It is then someone else's responsibility to work harder to support this person, which can be a waste of time. It can be solved with close watch by the lecturer.* [A55]

In total, it seems that 50% of the students, before exposure to CPPS, experienced an unequal contribution by team members as a problem during group work. Some of them tried to address the problem, but it is not clear whether it was solved. In contrast, 28% of students (Table 5.2) reported an unequal contribution as a problem they experienced during CPPS. It seems fair to conclude that an unequal contribution is less of a problem during CPPS than during group work prior to students' exposure to CPPS.

Comparing less dominant themes before and after exposure to CPPS becomes problematic as aspects that students had problems with during CPPS, such as random allocation of partners, were not part of their experience of group work prior to their exposure to CPPS.

5.6.2 University B

The answers to the two open-ended questions after exposure to CPPS, are analysed first. One hundred and ninety-six questionnaires were received back.

5.6.2.1 First question, after exposure to CPPS

Eighty-six students provided an answer to question one: “If relevant, please provide example(s) of something you have learned because of CPPS that you would not have learned if you were working alone.”

Two students provided two answers, but six answers were not applicable resulting in eighty-two answers. The answers were analysed using data driven codes. The codes were grouped under themes which are shown in Table 5.5.

Table 5.5: Themes for answers to the first question after exposure to CPPS, University B

THEME	Number of answers	%
CPPS facilitated learning	45	55
Diverse positive answers	5	6
Negative perceptions	21	26
Positive social outcomes	11	13
TOTAL	82	100

Of the 55% students who said CPPS facilitated learning, approximately a half said that they learned how to perform a certain action or execute a strategy: *I have learned how to do mass balances and energy balances.* [B158] And: *[I have learned] how to interpolate on a pocket calculator.* [B1] A few said that their understanding complemented each other: *It is much better to work with someone because one may know something the other one doesn’t and vice versa.* [B187] A few specifically mentioned their partner: *There were several times when I did not know what to do that the other person helped me or showed me which equations to use.* [B159] Some said that they learned another approach: *I would not have learned how to think a little bit differently when I encountered problems that I did not understand properly.* [B109] And: *I have learned to think differently than the way I am used to.* [B110] A few said they were made aware of small gaps in their own thinking: *Small detail in equations that I have overlooked.* [B6]

The theme “diverse positive answers” is related to learning: *I have learned to prepare much more thoroughly for class.* [B91] And: *I was forced to pay attention and make a contribution.* [B41] It seems therefore justified that the theme “diverse positive answers” (6%) can be combined with the theme “CPPS facilitated learning” (55%) to give an indication of the extent to which CPPS was perceived as a learning environment (61%).

Twenty six percent of the students raised negative aspects. Several were unhappy with the fact that they could not choose their partners. One had a particularly strong opinion: *I know this is* *not an answer to the question but I think CPPS is stupid! I prefer to work with someone who I am comfortable with, who I understand and with whom I can work productively. I am selfish and want to work with my intelligent friends. I do not want to make new buddies.* [B7] Several said: *[I have learned] nothing.* [B127]

A few complained about unequal contributions, *[I have learned] that everywhere in life there are parasites and that group work only benefits the weaker student at the cost of the better student.* [B64]

Thirteen percent of the students mention positive social outcomes. Some mention learning group work skills: *I have learned to communicate better, work in a team to solve problems and listen to everybody's inputs.* [B129] Others mention getting to know other people better: *[I have learned] that my perception of unfamiliar persons was completely wrong. I have met new people who I previously avoided because they appeared to be very egocentric.* [B145]

5.6.2.2 Second question, after exposure to CPPS

Sixty-nine students answered the second question, "If relevant give an example of a problem experienced by a CPPS group you belonged to and explain how the problem was solved (if at all)." Eleven answers were not applicable, resulting in fifty-eight answers. The answers were analysed using data driven codes. The codes were grouped under themes that are shown in Table 5.6.

Table 5.6: Themes for answers to second question after exposure to CPPS, University B

THEME	Number of answers	%
Problematic cooperation	19	33
Negative perceptions	9	16
Solved a tutorial problem	17	29
No Problem	13	22
TOTAL	58	100

Problematic cooperation included conflict: *He would not agree with the input values on the paper. I left him alone until he realised his calculations does not work out.* [B74] There were also communication problems: *Language gap. I had to quickly learn to say all the terms in English.* [B112] Several students also mentioned an unequal contribution by partners: *One guy was unprepared and did not help.* [B55] It was not always clear from the answers but it does not seem that problematic cooperation is a general problem. It often seems that the student was referring to a single incident.

Sixteen percent had negative perceptions which included that they would like to choose their own partners: *Must have the freedom to choose your own partner.* [B10] Some preferred to work alone: *I did not attend all tutorial sessions because I am a strong introvert and do not want to be forced to work with other people.* [B170]

Twenty nine percent of the students said that the problem that they experienced was a tutorial problem which they solved: *There were times that I and my partner were unsure about a problem. We then obtained help from other groups.* [B125] And: *When we had difficulty solving a problem, we asked a fellow student or the assistant or the lecturer.* [B93]

Twenty-two percent of the students said that they did not experience any problems, and gave answers such as*: Did not experience any problems.* [B181] And: *Cannot think of a specific incident.* [B142]

5.6.2.3 Comparing answers in the questionnaires filled in before and after exposure to CPPS, University B

Before exposure to CPPS students were asked to complete the questionnaire to provide a baseline for the students' experience of group work. Two hundred and one questionnaires were received back.

5.6.2.3.1 First question, before exposure to CPPS

One hundred and sixty-two students provided an answer to Question 1, "If relevant, please provide example(s) of something you have learned because of group work that you would not have learned if you were working alone." The codes were grouped under themes that are shown in Table 5.7. Nine answers were not relevant.

Table 5.7: Themes for answers to first question before exposure to CPPS, University B

THEME	Number of answers	%
Group work facilitated learning	76	50
My group work skills improved	72	48
Negative perceptions	3	2
TOTAL	153	100

Half the students (50%) said that group work facilitated their learning. Approximately a third of this group said that working together leads to a better outcome for everyone: [*I have learned] that one often arrives at a better solution if there are more than one perspective on the matter.* [B94] And: *Some people understand different parts of the problem better than others. By* *combining their understanding everybody can understand everything.* [B80] Another third said that group work helped them to see another perspective on the work: *By seeing the problem from someone else's point of view sometimes aids understanding.* [B155] And: *In a group one person have a better understanding than the rest and therefore can help everybody.* [B52]

The rest said that they learned something: *In the Physics practical in my first year, group work helped me to understand electricity.* [B20]

Compared to the 50% of students above who said that group work facilitated their learning 61% (55% + 6%) of students reported that CPPS facilitated their learning (paragraph 5.6.2.1) which indicates that CPPS is at least as good as other forms of group work in facilitating learning.

Forty eight percent (48%) of the students said that their social skills improved during group work: *[I have learned] how to manage conflict and take others into consideration.* [B110] And: *I have improved my ability to work with people and how to communicate.* [B66] Only thirteen percent of students (Table 5.5) mention positive social outcomes of CPPS and of those only a few mentions an improvement in group work skills. It is only possible to speculate about the possible reasons for the much smaller prominence in the students' answers of group work skills during CPPS. One possibility is that CPPS does not require well-developed social skills and that most students possess sufficient social skills to cooperate successfully.

Negative perceptions about group work increased from 2% before exposure to CPPS to 26% after exposure to CPPS. This increase in negative perceptions was mainly due to random partner allocation during CPPS.

5.6.2.3.2 Second question, before exposure to CPPS

The answers to the second question supplied by students before exposure to CPPS, "If relevant give an example of a problem experienced by a group you belonged to and explain how the problem was solved (if at all)", were analysed and the number of answers per theme is shown in Table 5.8. One hundred and thirty-nine students provided answers of which nine answers were not applicable.

Table 5.8: Themes for answers to second question before exposure to CPPS, University B

THEME	Number of answers	%
Problems during cooperation	50	38
Unequal contribution not solved	37	28
Unequal contribution addressed	23	18
Successful cooperation	20	15
TOTAL	130	100

Thirty eight percent (38%) of the students said that they experienced problems during cooperation. A variety of problems are mentioned, for instance, conflict: *Everybody had his own opinion and almost nobody could agree*; [B71] and lack of communication: *Poor communication between members of the group with the result that work was not completed.* [B11] It seems that in approximately half of these cases some sort of solution was found: *Groups of which I was a member sometimes experienced the problem of poor communication. It can be solved by giving everybody a chance and listening to everyone.* [B90] And: *A quarrel because of a difference in opinion. We then agreed on a common goal and everybody tried to put personal problems aside and focus on the goal.* [B38]

Twenty eight percent (28%) of the students mention that group members who do not contribute equally, is a problem they experienced during group work. Some say in so many words that the problem is not solved: *[A problem I experienced] was that only certain team members did all the work in order to get good marks. The rest did not contribute anything. It was never solved.* [B157] And: *Not everyone contributes equally. It is usually ignored.* [B147] Sometimes only a statement is made: *[The problem is] group members who do not do their part.* [B39] Sometimes the underperforming member is kicked out of the group (which is not a solution): *[The problem was] a guy who did not cooperate. We kicked him out of the group.* [B62] Or the underperforming member is penalized: *One person did not contribute. He was not given any credit.* [B82]

Eighteen percent (18%) of the students said they addressed the problem. Sometimes it seems that talking was enough and the problem was solved: *Not everybody cooperated and contributed equally. The matter was addressed and the problem solved.* [B47] Sometimes it can only be assumed that the problem was solved: *Everybody did not work equally hard, they were addressed sternly and asked to cooperate.* [B141] Sometimes only a suggestion is made on how to solve such a problem: *If a person does not do his bit, it is best to talk to this person* *without causing conflict.* [B83] It was not clear whether this approach was used with any success.

From the answers given above by students before their exposure to CPPS cooperation in groups did not go smoothly. Thirty-eight percent of these students experienced problems during cooperation and twenty-eight percent reported problems with an unequal contribution. This is almost two thirds (38 + 28 = 66%) of the students before exposure to CPPS. Only thirty-three percent of students reported problems with cooperation during CPPS (see Table 5.6).

5.6.3 Summary: Two open-ended questions

The sentiments expressed by students in reaction to the two open-ended questions are in good agreement with what transpired during the interviews.

Many students felt that CPPS created an environment that facilitated learning. Many mentioned that their partners made them aware of small errors that they made or that they gained a lot, such as learning a new strategy – instances of uni-directional help. Many also mentioned that often they both found mutual benefit from working together (bi-directional help).

Some mentioned instances of problems during cooperation such as an unequal contribution by partners. Students again expressed dissatisfaction with the fact that they could not choose their own partners.

This concludes the analyses of data gathered using qualitative methods. The following quantitative analyses are subsequently done:

- the analysis of the answers to the Likert-scale questions in the student questionnaire. The aim of the Likert-scale questions was to determine to what extent the students experienced the structuring of the elements of CL (research subquestion 2) and the perceptions of the CPPS procedure (research subquestion 3);
- the analysis of the results of the quasi-experiment to determine the effect of CPPS on students' academic performance (research subquestion 4) as well as the effect of attending the CPPS tutorials had on academic performance in 2013, 2014, 2015 and 2016, and
- the analysis of the results of a quasi-experiment to determine the effect of CPPS in students' understanding of Thermodynamic concepts (research subquestion 5).

5.7 Student questionnaire: Quantitative analysis of the Likert-scale statements

The questions in the questionnaire were formulated in such a way as to gauge the extent to which the students experienced the structuring of the five elements of CL as well as their perception of CPPS. A factor analysis on their responses after their exposure to CPPS was performed to determine which statements correlated well with each other. To provide a baseline, the students were also asked to complete the questionnaire before their exposure to CPPS. The same questions were used but instead of CPPS, the term *group work* was used. A dependent *t*-test was then performed to determine significant differences in the responses before and after exposure to CPPS to the seventeen questions existed.

These two aspects, the dependent *t*-test and the factor analysis will now be discussed separately.

5.7.1 Factor analysis

The way the students experienced the tutorials are reflected in their responses to the 17 statements on the questionnaire. Their responses could vary between "do not agree at all" (1) to "fully agree" (4). The first step in a factor analysis is to determine whether there was correlation between answers to the statements. Two statements will correlate well if the students who agreed (or disagreed) to one statement also agreed (or disagreed) to the second statement. The statements whose answers correlated well with each other were then studied to determine whether there was a common theme which bound them together. This common theme is called a factor. The correlation coefficient of each individual statement with the factor was also determined.

Some of the factors could be linked directly to one the principles of CL. The four questions that correlated well with the factor positive interdependence for both universities are shown in Table 5.9. The correlation coefficient between each statement and the factor (CC) as well as the average and standard deviation (SDev) of the answers to each statement are shown.

The number of the question in the questionnaire is indicated in the leftmost column.

For university A, the results from 258 questionnaires and for university B, the results from 163 questionnaires were used in the analysis.

Table 5.9: The existence of positive interdependence between partners

No	STATEMENT	CC	Average Sdev	
			A	B
1	During CPPS both team members contributed equally towards attaining the group's goal.	0.788	2.41 0.84	2.97 0.79
9	During PPS both team members were up to date with the problem we were working on.	0.678	2.03 0.80	2.55 0.88
8	Both the team members benefitted equally from working together.	0.640	2.27 0.84	2.71 0.88
2	I learned more by working with someone compared to working on my own.	0.508	2.64 0.97	3.04 0.89
Factor			2.34 0.65	2.82 0.68

For this factor, the Cronbach alpha is 0.796 and the mean inter-term correlation 0.496 which indicates a very high level of internal consistency for these questions. The students' reponses could vary between from "do not agree at all" (1), "agree to a small extent" (2), "agree to a large extent" (3) to "fully agree" (4). Therefore a factor average of 2.82 for University B indicates that the students essentially agreed that positive interdependence existed at University B.

The factor average for University A is 2.34. The effect size (0.71) of difference between these two factor averages for the two universities (2.82 and 2.34) indicates that the university had a significant effect on the extent to which students at the two universities experienced positive interdependence. According to Cohen, d = 0.2 should be considered a small effect size, d = 0.5 a medium effect size and 0.8 a large effect size. A careful observer will notice the difference in two populations with a medium effect size (Field, 2013).

Five questions that correlated well with the factor face-to-face promotive interaction are shown in Table 5.10. For the calculation of the statistics of this factor we reversed the scores of Question 3 and Question 17.

Table 5.10: Face-to-face promotive interaction

No	STATEMENT	CC	Average SDev	
			A	B
3	Conflict regularly occurred during CPPS.	-0.513	1.55 0.71	1.55 0.76
5	During CPPS my team mate listened to my contributions.	0.455	3.05 0.69	3.18 0.67
17	CPPS increased my stress levels.	-0.376	2.27 1.06	2.13 0.93
14	During CPPS I had enough confidence to ask my team mate questions.	0.355	3.09 0.86	3.35 0.67
13	During CPPS the two of us helped each other	0.323	2.98 0.72	3.15 0.69
Factor			3.06 0.53	3.20 0.50

The Cronbach alpha for this factor is 0.67 and the mean interterm correlation 0.30. The high averages for this factor ($\bar{x} = 3.06; 3.20$) is indicative of the fact that students at both universities helped each other and that effective working relationships existed in the groups.

Three questions correlated well with a factor “individual responsibility” and are shown in Table 5.11:

Table 5.11: The extent to which students felt personally responsible

No	STATEMENT	CC	Average SDev	
			A	B
10	During CPPS my contribution was necessary for the group to be successful.	0.689	2.91 0.70	2.98 0.58
4	During CPPS I could use my unique abilities to the advantage of the group.	0.475	2.66 0.79	2.87 0.64
11	During CPPS I felt a sense of responsibility towards my group.	0.464	2.95 0.80	3.11 0.69
Factor			2.84 0.59	2.99 0.47

For this factor, the Cronbach alpha is 0.64 and the mean interterm correlation 0.376. The averages for this factor indicates that the students at both universities essentially agreed that they felt a sense of responsibility towards the group.

Two questions related to the social advantages due to CPPS correlated well and is shown in Table 5.12.

Table 5.12: The social benefits of working together

No	STATEMENT	CC	Average SDev	
			A	B
6	CPPS taught me to cooperate better with other people.	0.867	2.55 0.91	2.72 0.90
16	CPPS helped me to fit in socially.	0.743	1.83 0.91	2.12 0.91
Factor			2.19 0.79	2.43 0.870

For this factor, the Cronbach alpha is 0.69 and the mean interterm correlation 0.53.

For both universities, the average for the factor is unexpectedly low. During the interviews, it became clear that many students did not like the fact that they could not choose their own partners. This could have had the result that students were reluctant to admit that CPPS had any social benefits.

Three questions correlated with a factor I called “synergy” and is shown in Table 5.13.

Table 5.13: Synergy in group work

No	STATEMENT	CC	Average SDev	
			A	B
7	During CPPS it was a waste of time to help my team mate.	0.531	1.65 0.79	1.78 0.97
15	CPPS is detrimental of the better student.	0.525	2.26 1.0	2.22 0.98
12	CPPS is simply a collection of individual efforts.	0.423	2.17 0.96	2.25 0.92
Factor			2.02 0.68	2.07 0.7

The Cronbach alpha for this factor is 0.56 and the mean interterm correlation 0.298.

It is important to note that unintentionally all the questions that grouped under this factor are reverse phrased and therefore the factor averages of 2.02 and 2.07 is an indication that students essentially agreed that they both found benefit in working together. The low average for Statement 7 is encouraging as it seems to indicate that students thought that helping a partner was not a waste of time. The reason for this could be twofold. Either the person providing help found benefit due to helping or they considered the gains made by the partner due to their help as a worthwhile endeavour.

5.7.1.1 Perception of CPPS

The questionnaire filled in after exposure to CPPS contained an extra question, “I would like to work like this again in a next subject.” The response could vary between 1 and 4 with 1 corresponding to “strongly disagree” and 4 with “strongly agree” The average for University A was 2.17 with a standard deviation of 1.1. The average at University B was 2.37 with a standard deviation of 1.0.

An analysis of the responses is shown in Figure 5.4.

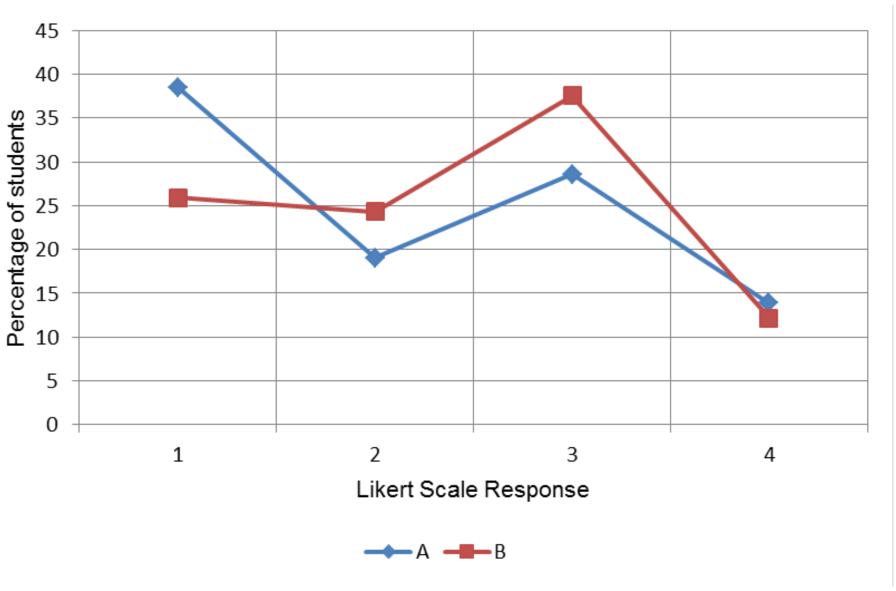

Figure 5.4: Analysis of responses to Question 18 for University A and B

For University A, 58% of the students either disagreed or strongly disagreed with 42% who either agreed or strongly agreed. For University B, 50% of the students either agreed or strongly agreed and 50% disagreed of strongly disagreed. As mentioned in paragraph 5.2.2.2, many students resented the fact that they could not choose their own partners. That could have influenced some students to indicate that they would not like to work “like this again in a next subject”.

5.7.2 Dependent *t*-tests

Students completed the questionnaire with the 17 Likert-scale statements before and after their exposure to CPPS. The answers to the statements before their exposure to CPPS provided an indication of their experience of group work up to that point and could also be used as a baseline against which to measure their answers to the statements after exposure to CPPS.

As discussed in paragraph 5.7.1, the answers to the Likert-scale statements grouped into factors, some of which were related to the elements of CL. Using these factors, the student responses before and after exposure to CPPS, will now be compared using a dependent *t*-test.

For the dependent *t*-test, only the data of students who completed both questionnaires (before and after exposure to CPPS) were taken into consideration. For the factor analysis in the previous paragraph (paragraph 5.7.1) of the student responses after exposure to CPPS, the responses of all students were included.

The average values for the statements in the dependent *t*-test in the next paragraph will therefore not be the same as the average values in the factor analyses in paragraph 5.7.1 as some students did not complete both questionnaires.

5.7.2.1 Positive interdependence

As discussed in paragraph 5.7.1, questions 1, 9, 8 and 2 correlated well with the factor positive interdependence. The averages of the answers to these statements as well as the factor, before and after exposure to CPPS, are shown Table 5.14.

Table 5.14: Results of dependent t- test on positive interdependence

No	STATEMENT	University	Avg Before CPPS	Avg After CPPS	Std Dev Before	Effect size
1	During group work / CPPS both team members contributed equally towards attaining the group's goal.	A	2.52	2.43	0.87	0.11
		B	2.34	2.93	0.77	0.75
9	During group work / CPPS both team members were up to date with the problem we were working on.	A	2.32	1.97	0.90	0.38
		B	2.34	2.51	0.80	0.22
8	Both the team members benefitted equally from working together.	A	2.35	2.22	0.90	0.15
		B	2.24	2.66	0.84	0.50
2	I learned more by working with someone compared to working on my own.	A	2.63	2.64	0.85	0.01
		B	2.68	2.95	0.89	0.31
	Factor	A	2.45	2.31	0.64	0.22
		B	2.41	2.76	0.62	0.57

Even though the average for the factor positive interdependence at University A decreased from 2.45 to 2.31, the effect size (0.22) is small and the difference would therefore not have been obvious. For University B, CPPS brought about a marked improvement in positive interdependence.

An important difference between the universities was that attendance at University A was compulsory while at B, attendance was voluntary. It is therefore conceivable that the students at University B could be more committed to contribute and cooperate, resulting in an environment where students relied more on each other.

5.7.2.2 Promotive interaction

Statement 3, 5, 17, 14 and 13 correlated well with the factor “promotive interaction”. The students' responses before and after exposure to CPPS are compared in Table 5.15.

Table 5.15: Results of dependent t-test on promotive interaction

No	STATEMENT	University	Avg Before CPPS	Avg After CPPS	Std Dev Before	Effect size
3	Conflict regularly occurred during group work / CPPS.	A	2.21	1.57	0.72	0.89
		B	2.26	1.55	0.71	1.00
5	During group work / CPPS my team mate listened to my contributions.	A	2.75	3.07	0.77	0.41
		B	2.74	3.12	0.71	0.53
17	Group work / CPPS increased my stress levels.	A	2.21	2.33	0.98	0.13
		B	2.18	2.14	0.89	0.04
14	During group work / CPPS I had enough confidence to ask my team mate questions.	A	3.37	3.11	0.70	0.37
		B	3.37	3.31	0.59	0.10
13	During group work / CPPS the two of us helped each other.	A	3.07	2.97	0.68	0.15
		B	3.12	3.09	0.56	0.06
	Factor	A	2.96	3.06	0.52	0.18
		B	2.95	3.17	0.43	0.49

Compared to their experience of group work prior to CPPS, conflict during CPPS at both universities was significantly lower (Statement 3) with effect sizes of 0.89 and 1 which corresponds to a large effect. The statistics for the factor shows that at University B, promotive interaction was noticeably better during CPPS (effect size 0.49) than during group work prior to CPPS. For University A, the improvement in promotive interaction would not have been noticeable with an effect size of 0.18.

5.7.2.3 Personal responsibility

Question 10, 4 and 11 correlated well with the factor “personal responsibility”. The students’ responses before and after exposure to CPPS are compared in Table 5.16.

Table 5.16: Results of dependent t-test on personal responsibility

No	STATEMENT	University	Avg Before CPPS	Avg After CPPS	Std Dev Before	Effect size
10	During group work / CPPS my contribution was necessary for the group to be successful.	A	3.19	2.94	0.83	0.30
		B	3.31	2.97	0.84	0.40
4	During group work / CPPS I could use my unique abilities to the advantage of the group.	A	3.07	2.65	0.76	0.56
		B	3.03	2.81	0.66	0.33
11	During group work / CPPS I felt a sense of responsibility towards my group.	A	3.29	2.95	0.68	0.51
		B	3.33	3.07	0.64	0.40
	Factor	A	3.19	2.85	0.56	0.60
		B	3.22	2.95	0.49	0.55

The averages for all the questions after exposure to CPPS are lower. The effect size for the factor shows that the extent to which students felt personally responsible during CPPS is noticeably less than during group work prior to CPPS. This is an unexpected result and the reasons can only be speculated at. It is possible that during CPPS, the group functioned well as a unit, with the result that students did not feel that they had to come to the rescue of the group.

5.7.2.4 Social benefits

Question 6 and 16 correlated well with the factor of social benefits. The students' responses before and after exposure to CPPS are shown in Table 5.17.

Table 5.17: Results of dependent t-test on social benefits

No	STATEMENT	University	Avg Before CPPS	Avg After CPPS	Std Dev Before	Effect size
6	Group work / CPPS taught me to cooperate better with other people.	A	3.07	2.57	0.81	0.62
		B	3.21	2.70	0.71	0.71
16	Group work / CPPS helped me to fit in socially.	A	2.26	1.82	0.97	0.46
		B	2.49	2.06	0.93	0.45
	Factor	A	2.66	2.19	0.79	0.59
		B	2.85	2.40	0.70	0.65

The averages of the answers for all statements as well as for the factor are significantly lower for CPPS than before with effect sizes indicating a medium to large effect. This is again unexpected and difficult to explain. As mentioned already in paragraph 5.2.2.2, during the interviews it became clear that many students did not like the fact that they could not choose their own partners. This could have had the result that students were reluctant to admit that CPPS had any social benefits.

5.7.2.5 Synergy

Question 7, 15 and 12 correlated well with the factor synergy. The averages before and after exposure to CPPS are shown in Table 5.18.

Table 5.18: Results of dependent t-test on synergy

No	STATEMENT	University	Before (Group work)	After (During CPPS)	Std Dev Before	Effect size
7	During group work / CPPS it was a waste of time to help my team-mate.	A	1.67	1.66	0.77	0.02
		B	1.79	1.83	0.80	0.05
15	Group work / CPPS is detrimental of the better student.	A	2.26	2.26	0.96	0.00
		B	2.27	2.22	0.87	0.05
12	Group work / CPPS is simply a collection of individual efforts.	A	2.34	2.23	0.91	0.12
		B	2.40	2.20	0.77	0.25
	Factor	A	2.09	2.04	0.58	0.08
		B	2.15	2.07	0.57	0.13

It is clear from the small values of the effect sizes that there were no significant differences between synergy obtained in a group prior to CPPS and during CPPS.

5.7.3 Summary of dependent *t*-tests

Compared to group work before CPPS, there was a noticeable improvement in positive interdependence during CPPS tutorials at University B. At University A, there was a barely perceptible deterioration in positive interdependence during CPPS tutorials when compared to previous experiences of group work. The reason may be that the attendance of tutorials was not compulsory at University B and that the students who did attend, accepted the responsibility to make the group “work” and cooperated with and relied on their partners. Promotive interaction at University B was noticeably better during CPPS tutorials while at University A the effect of CPPS on promotive interaction was minute. Conflict during CPPS tutorials at both universities was lower with an effect size indicating a large effect.

Students felt noticeably less responsible for the CPPS group. They also felt that the social benefits of CPPS were less than other groups they belonged to prior to their exposure to CPPS. It is possible that the fact that they could not sit with friends made them reluctant to admit that CPPS had social benefits. The synergy obtained during CPPS was at the same level as synergy obtained during group work prior to CPPS.

5.8 Academic performance

5.8.1 Background

To determine whether attending CPPS tutorials improved students’ academic performance, the academic performance of the students who attended the CPPS tutorials (the 2013 or experimental group,) was compared to the students who attended tutorials that was presented as usual (the 2012 or control group). A covariant calculated from the students’ marks in their last school year, was used to compensate for a possible difference in intelligence between students of the two groups. No significant difference between the experimental and control groups (at both universities) could be found. Several factors that differed between the control and experimental groups could not be controlled or corrected for during a statistical analysis: At University A, some of the staff presenting the lectures as well as the lecturers presenting the tutorials in 2013 were new or were not involved in 2012. At both universities, new tests and examination papers are set up every year.

It was therefore decided to investigate the effect that the number of tutorials attended by a student had on his academic performance. At University A, all students taking the course for the first time, were expected to attend all the tutorials. Only students with valid reasons, such as a doctor's appointment, were excused. Therefore, the variance in the number of tutorials attended was not sufficient to make a statistical analysis worthwhile. At University B, attendance of tutorials was not compulsory and the variation in number of tutorials attended by the different students was sufficient to make a statistical analysis possible. Furthermore, at University B, the CPPS strategy was used again in Thermodynamics tutorials in 2014, 2015 and 2016 which increased the amount of data that could be analyzed.

5.8.2 Compensating for the effect of intelligence and diligence

The possible positive effect of attending the CPPS tutorials could be confounded with the effect of the diligence and intelligence of a student, as it is possible that the diligent student will study hard and therefore obtain high marks and attend the tutorials because he or she is a diligent student. It is also possible that a lazy student will not attend the CPPS tutorials and score poorly because he or she does not study enough. To make a proper analysis possible, some sort of indication is necessary of the intelligence and diligence of students.

The correlation between the marks obtained in 2011 and 2012 in Thermodynamics and several other subjects were investigated and it was found that an average mark of Applied Mathematics (TGWN 211) Mathematics (WISN 211) and Electric Circuits (EERI 228) correlated well with the marks obtained in Thermodynamics. The average marks obtained by a student in these three subjects were therefore used as an indicator for diligence and intelligence.

The agreement between the indicator and marks obtained in Thermodynamics for 2012, the year before CPPS was implemented, is shown in Figure 5.5.

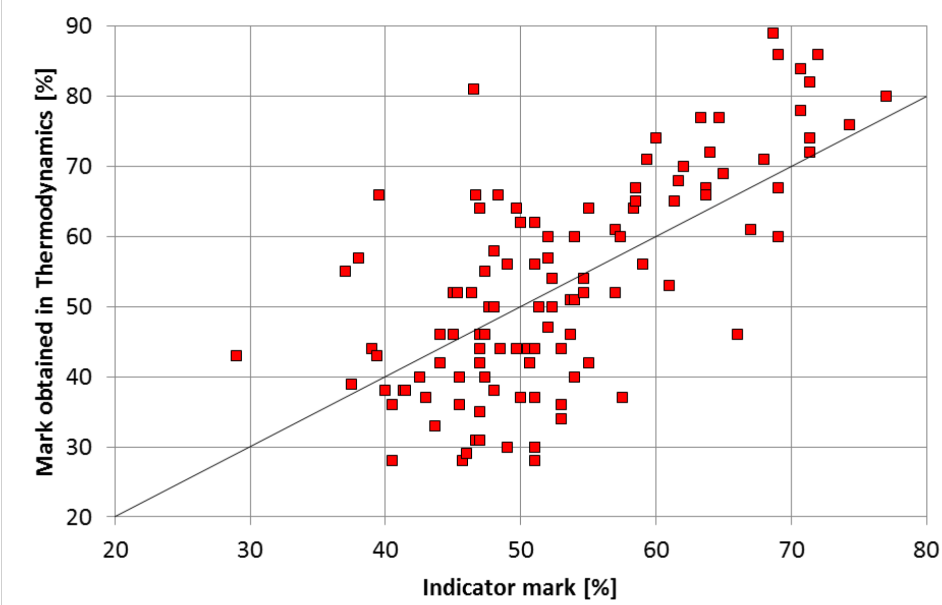

Figure 5.5: The correlation between the indicator and thermodynamic marks

Many students with an indicator mark at the lower end obtained even lower marks in Thermodynamics, while students with higher indicator marks did somewhat better in Thermodynamics. The correlation coefficient between the indicator marks and the marks obtained in Thermodynamics for 2012 is 0.69. The same pattern was evident in 2011 with a correlation coefficient of 0.78.

From a visual inspection of the data of 2016[5] in Figure 5.6, there seems to be a difference between the final scores of students who attended all seven tutorials (or missed only one) and the final scores of students who attended no tutorials or attended only one. (The two groups are identified in the graph with '6-7' and '0-1' to indicate the number of tutorials attended.) Students who attended 2,3,4 and 5 tutorials are not shown as that would have obscured the picture.

It is clear from the graph that most of the students who attended most or all CPPS tutorials ('6-7'), did better than expected while the students who attended one or no CPPS tutorials ('0-1'), generally obtained marks as expected. This effect will now be investigated in greater detail.

[5] The results for 2016 are shown here because it illustrates the point the best.

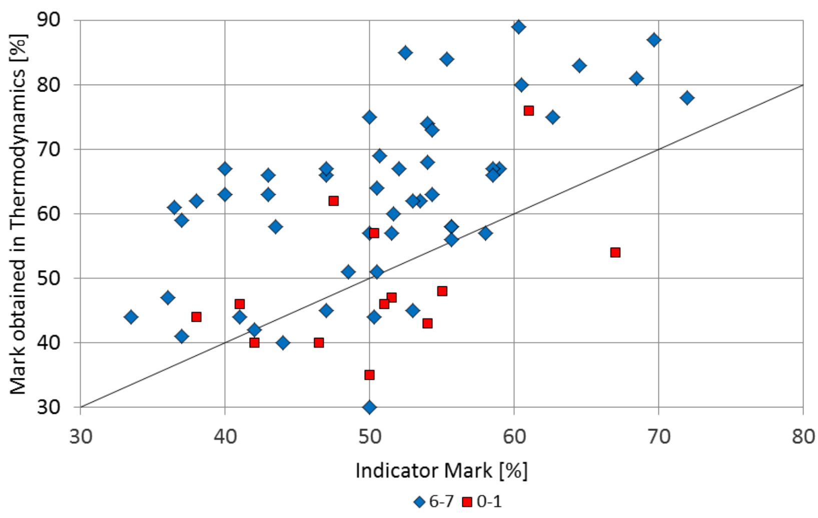

Figure 5.6: Effect of attending CPPS tutorials on academic performance in 2016

5.8.3 Analysis of final marks

The number of students attending a specific number of tutorials was sometimes small, which made statistical inferences less meaningful. It was therefore decided to cluster students in three groups: The students who attended one or no tutorials (the 0-1 group), the students who attended two or three tutorials (the 2-3 group), and the students who attended four or more tutorials (the 4-7 group). Students who would fall into the 0-1 group would be students who attended the first tutorial and decided they do not like the CPPS strategy, or are repeating the subject and had scheduling problems. It was felt that attending only two or three tutorials would perhaps not be enough to accrue any significant benefit from the CPPS procedure (if there were any), whereas attending four or more of the seven tutorials would be sufficient to make a noticeable difference. A preliminary statistical analysis also confirmed that this was sensible clustering of number of tutorials attended.

An analysis of covariance was performed on the data to determine the effect of the number of tutorials attended on the final marks obtained in Thermodynamics.

The indicator for diligence and intelligence was used as covariate. The final marks obtained in Thermodynamics were adjusted to make provision for the effect of differences in diligence and intelligence. The results for the four years CPPS are shown in Table 5.19.

Table 5.19: Statistical analysis of final marks obtained in Thermodynamics

		Year CPPS was implemented			
		2013	**2014**	**2015**	**2016**
Mean Square (MS) Error		157.2	132.9	95.5	210.5
MS Attendance of tutorials		393.3	2.5	168.2	853.1
Significance (*p* value)		0.086	0.982	0.175	0.019
		Adjusted mean of final marks [%]			
Number of tutorials attended	0-1	53.6	58.0	52.8	53.7
	2-3	53.7	57.9	51.2	56.7
	4-7	58.4	57.5	55.1	62.1
		Effect size of comparison			
Comparisons	0-1 with 2-3	0.01	0.00	0.17	0.2
	2-3 with 4-7	0.38	0.04	0.40	0.58
	0-1 with 4-7	0.39	0.04	0.23	0.37

The probability that the differences in the adjusted final marks obtained by the different groups (0-1, 2-3 and 4-7) in 2013 (53.6%, 53.7% and 58.4%), are due to chance, is 8.6% (p = 0.086). The adjusted average mark obtained by students attending four or more tutorials (the 4-7 group in the table) is greater than the adjusted average mark obtained by students attending three or fewer tutorials (the 0-1 and 2-3 groups in the table). The effect sizes indicate that attending four or more tutorials had a moderate effect (effect size 0.38) on the final marks when compared to the final marks of the group attending only two or three tutorials. Attending four to seven tutorials also had a moderate effect (effect size 0.39) on the final marks compared to the group who attended no or only one tutorial.

In 2014 there is almost no difference in the average marks obtained by the different groups. The probability that the differences that do exist are due to chance, is 98.2% (p = 0.982) which indicates that attending CPPS tutorials probably had no effect on the final marks. Comparing the averages of the 0-1 groups of different years shows that the average obtained by students attending one or no tutorials in 2014 is higher than the average for the same group for other years. A possible reason for this high average mark is the fact that 71% of the students attending one or no tutorials in 2014 were students repeating the subject. The corresponding percentage of students repeating the subject for other years are as follows; 2013: 56%; 2015: 47%, and 2016: 54%. Students repeating the course had already been exposed to the content and studied for tests and even examinations and that may have helped them to achieve higher marks is spite of the fact that they did at most, attended only one tutorial.

Although the effect sizes in 2015 indicate that attending four or more tutorials had a moderate effect on final marks obtained, the probability that the differences in the adjusted final marks obtained by the different groups are due to chance, is 17.5%. For 2016, the differences in the adjusted means between the different groups are the largest of all the years and the probability that the differences are due to chance is only 1.9%. The magnitude of the effect sizes indicates that attending four or more tutorials has a noticeable effect on the adjusted final mark obtained compared to students who only attended two or three tutorials. Despite the encouraging results obtained in 2016, the data was analyzed further to eliminate possible other confounders of the effect of attending tutorials.

5.8.4 Analysis of participations marks

The final mark in Thermodynamics was a combination of the participation mark and the mark obtained during the examination, the examination mark contributing 60% and the participation mark 40%. Eighty-five percent of the participation marks were made up of marks obtained by the student in three tests spaced equally throughout the semester. (The other 15% was from two practical sessions.) As the tests making up the participation mark were taken during the semester, with the tutorials still fresh in the minds of students, the effect of attending CPPS tutorials (or not) could have been more pronounced when taking the tests than during the final examination. Furthermore, in preparation for final examinations students often have more time to prepare, make use of other resources and focus their effort on one subject at a time. It was therefore decided to investigate the effect of number of tutorials attended on the participation mark. The indicator mark was again used as covariate. The results are shown in Table 5.20.

Table 5.20: Effect of the number of tutorials attended on the participation mark

		Year CPPS was implemented			
		2013	**2014**	**2015**	**2016**
Mean Square (MS) Error		177.3	131.5	158.7	252.7
MS Attendance of tutorials		898.1	240.5	1009.5	3327.4
Significance (*p* value)		0.07%	0.164	0.002	0.000
		Adjusted mean of participation marks [%]			
Number of tutorials attended	0-1	49.7	54.2	48.6	39.7
	2-3	52.1	52.3	47.6	52.1
	4-7	58.0	56.6	55.0	55.9
		Effect size of comparison			
Comparison	0-1 with 2-3	0.18	0.17	0.08	0.78
	2-3 with 4-7	0.45	0.38	0.59	0.24
	0-1 with 4-7	0.62	0.21	0.51	1.02

For 2013, 2015 and 2016, the probability that the variation in participation marks between the groups attending a different number of tutorials, is due to chance is reduced to less than 1% ($p < 0.01$). For 2014 the probability that the variation is due to chance is much lower than in Table 5.19, but still a high 16.4%. The reason for this high value is again the high average participation mark obtained by students attending one or no tutorials. The reason for this higher participation mark could again be the large percentage of students in the 0-1 group who repeated the subject.

It is encouraging to note that the effect sizes for 2013 (0.45), 2014 (0.38) and 2015 (0.59) indicate that attending four or more tutorials had a strong to moderately positive effect on the participation mark when compared to the participation mark obtained by students attending only two or three tutorials. It can be argued that to really find benefit from the tutorials students need to attend more than half the tutorials which is four tutorials out of seven. In 2016, the average marks obtained by the group who attended two or three tutorials (52.1%) is significantly larger than the average marks obtained by the group who attended only one or not tutorials (39.7%). The effect size of 0.78 for this difference is the largest for all the years. This large effect size is due to the comparatively low average participation mark (39.7%) of the students attending one or no tutorials.

The effect size for the average participation marks between students attending two and three tutorials and students attending four or more tutorials in 2016, is 0.24 which corresponds to a small effect. However, it should be noted that, as mentioned already in the discussion of the final marks, the effect size between the same groups of students (students attending two and three tutorials and students attending four or more tutorials) in 2015, is the highest for all the years. It seems that the effect of the number of tutorials attended in 2016, is not reflected as strongly in the participation marks as in the final marks.

5.8.4.1 Attendance of CPPS tutorials

Whereas attendance of tutorials at University A was compulsory, attendance at University B was voluntary. Attendance figures of tutorials at University B would therefore give an indication of the perceptions of students of CPPS. Over the four years that CPPS has been implemented at University B, almost two thirds (65.5%) of the total number of students enrolled for Thermodynamics attended the CPPS tutorials. This is a dramatic improvement over the 10-20% attendance of previous years. This increase in attendance is an indication that students, despite any reservations they might have had, felt it worth their while to attend the tutorials.

5.9 Concept tests

The relationship between problem-solving skill and conceptual understanding was explored in paragraph 2.5. The concept test by Miller et al. (2011) was rigorously developed and validated. However, it contained questions that would be misunderstood by students at the universities where this study was conducted, and could not be used. A new concept test was therefore developed as described in paragraph 4.6.3.2

The only variable in this study was the implementation of CPPS during tutorials. The goal was therefore to test whether CPPS alone had any effect on the conceptual understanding of students.

The concept test was taken by the groups at both universities, where tutorials were conducted in the traditional way (2012 group) and their scores compared to the scores of the 2013 groups, where CPPS were implemented during tutorials. The scores obtained in the concept test were analysed using an ANCOVA with the marks obtained during the students' final school examination as co-variant. The results are shown in Table 5.21.

Table 5.21: Effect of CPPS on conceptual understanding

University	Group	Score (%)	Std. Error	Effect size
A	Control	57	9.1	0.38
	Experimental	50	11.3	
B	Control	49	11.3	0.10
	Experimental	50	7.7	

CPPS had no noticeable effect on the conceptual understanding of students at University B, but students at University A exposed to CPPS did even worse, probably due to the differences in lecturers that taught the two groups. At University B, conditions between the two years were very similar.

While it is not possible to objectively rate the scores obtained in the concept test, it was well below the (subjectively) expected score, with three of the four groups scoring around 50%. This low score is in line with the experience of other instructors assessing their students' conceptual understanding after traditional instruction (Felder & Brent, 2016). It seems therefore clear that while CPPS may help students to solve problems and even achieve better grades this improvement may be due to improved problem solving skills and not better conceptual understanding (Case & Marshall, 2004). Improving conceptual understanding may require measures targeted specifically at improving the understanding of fundamental concepts.

5.10 Summary

In this chapter the analysis of the empirical results were discussed. The chapter is organized around the analysis of each data gathering instrument.

The qualitative data was analysed first. The interviews with the students were analysed for the structuring of the five elements of cooperative learning and their perceptions of CPPS. The themes for the perceptions of the students were derived from the data. Next, the answers to the six open ended questions in student assistant questionnaire were analysed. The observer reports were analysed for the observers' perceptions of the structuring of the element of cooperative learning and the researcher's journal was analysed for perceptions of CPPS.

The students answered a questionnaire before and after exposure to CPPS. The large number of questionnaires received back, made it possible to derive the strength of codes and themes that emerged from the answers to the two open-ended questions at the end of the questionnaire. The answers to the two-open ended question before and after exposure to CPPS were also compared.

The quantitative data were then analysed.

Using a factor analysis, the answers to the Likert-scale questionnaire were analysed for the structuring of the five elements of cooperative learning. The results from the quasi-experiment were analysed to determine the effect of CPPS on academic performance and conceptual understanding. A correlational analysis was used to determine the effect of the number of tutorials attended on academic performance.

The results from the empirical investigation can be summarized as follows:

There is agreement between the results from the student interviews, answers to the open-ended questions, student assistant questionnaires and observer reports that CPPS created an effective learning environment and facilitated learning. Generally, the two team members considered each other as an asset: someone who can complement your own understanding; who can provide a different perspective; compensate for your own incomplete understanding; someone with whom you can plan and execute the problem-solution strategy, and confirm and check your own understanding and calculations. The fact that CPPS provided such an effective learning environment dramatically reduced the teaching load on the instructor.

It was also found that working with strangers generally increased the efficiency of the cooperation between students for a variety of reasons. However, the random allocation of partners was a contentious issue amongst students. Even though most recognized the advantages of working with strangers, and a substantial number accepted the arrangement, it still seemed that most students would have preferred to choose their own partners.

With regards to group formation it seems that students could be divided into five categories which played an important role in determining their attitude towards CPPS: The conscientious student, used to working with like-minded friends; The free-loader, used to feed off stronger, better prepared students; The outsider, for whom CPPS provided an welcome opportunity to work with someone and perhaps even make new friends; The extrovert, who derived energy and enjoys working with anyone; and the strong introvert or shy student who would rather have worked on their own.

While positive interdependence was structured into the procedure, and conditions created that made it advantageous for students to rely on each other, the strength of the positive interdependence was also affected by the extent to which students took responsibility to make the group effective, to cooperate, help, and rely on their partners. There is ample evidence that most students, as mentioned already, considered their partners as an asset and that both found benefit from working together and coordinating their actions. It is also clear that students possessed sufficient social skills to cooperate harmoniously in groups of two.

The quantitative data for University B showed that attending more than 50% of the tutorials had a moderate to strong positive effect on students' academic performance as reflected in their participation marks.

However, there was no improvement in the conceptual understanding of the groups exposed to CCPS when compared to the groups where tutorials were conducted the normal way. This is in line with the literature which states that specific, dedicated measures are required to teach students the fundamental concepts.

CHAPTER 6
CONCLUSIONS, RECOMMENDATIONS, AND FINAL REMARKS

6.1 Introduction

In previous chapters Thermodynamics was considered from a teaching-learning perspective, a theoretical framework for thermodynamic problem solving in groups was proposed, and the methodology and results of the empirical investigation was described and discussed. In this chapter, the focus is on answering the main research question and research subquestions by drawing from the previous chapters. To conclude the chapter, the limitations of the study is considered and recommendations and final remarks are made.

6.2 Answering the research questions

The main research question is: How can a cooperative pair problem solving strategy (CPPS) be designed for Mechanical Engineering Thermodynamics tutorials and how successful is its implementation? To answer this question, two aspects are considered.

Firstly, using the understanding provided by the theoretical framework developed in paragraph 3.2, a procedure was developed where students solve problems together in pairs. The desired behavior is that students should rely on and help each other. This behavior is promoted by manipulating the environment and includes steps to strengthen the perception of students that they need to work together to succeed. The social interdependence theory and the social constructivist theory are used to inform the social cognitive theory. The well-established elements of CL developed by Johnson et al. (2008) are structured in the procedure.

Secondly, the success of CPPS is evaluated by considering three aspects: (a) The extent to which students (and other role players) experienced the five elements of CL during CPPS. In other words, how successful was the structuring of the five elements? (b) The perceptions of the different role players of CPPS. In other words, how successful (apart from the structuring of the five elements) and viable was CPPS according to the role players?

(c) What were the effect of CPPS on the academic performance as well as conceptual understanding of students? In other words, how successful was CPPS as a teaching-learning strategy?

The design of CPPS and the structuring of the elements in CPPS are now discussed.

6.2.1 Structuring the five elements of CL in cooperative pair problem solving

The first research subquestion was: How can the five elements of CL be structured in the design of CPPS?

In this paragraph, the structuring of the elements of CL in CPPS is discussed. The extent to which this structuring was successful is only evaluated in paragraph 6.2.2, when the second research subquestion is answered.

According to Johnson and Johnson (2013) positive interdependence forms the basis of CL and will be discussed first.

6.2.1.1 Positive interdependence

In the case of CPPS, several synergistic measures were taken to strengthen the perception of the two partners that they must coordinate their efforts to complete the task. An important step was to make the problems sufficiently challenging that the solution was not immediately obvious and that setting up a solution strategy was necessary. The goal was to make it advantageous for both partners to coordinate their understanding and mental efforts when setting up the strategy. Average students would have found it difficult to complete the problems on their own in the allocated time (paragraph 3.3.1.1). The students were encouraged to rely on each other, share resources and divide the different tasks between themselves, such as looking up values in tables, calculating values and finding equations in the textbook (task and resource interdependence).

The two students sat next to each other (environmental interdependence) and each pair received only a single hard copy with the problems (resource interdependence). The two students had to provide a single answer for each problem (goal interdependence). They were awarded the same mark for this joint effort (outcome interdependence). As discussed in paragraph 4.9.6, at both universities the marks accumulated by a student during tutorials contributed towards the final grade awarded for this subject.

Positive interdependence was therefore actively promoted by creating conditions that strengthened the perception of students that they needed to coordinate their efforts to solve the problems on time, as well as taking measures to structure various forms of positive interdependence.

6.2.1.2 Promotive interaction

Promotive interaction is characterized by students behaving in a certain way; by helping each other and accepting co-responsibility for the success of the group in solving problems (Johnson & Johnson, 2013, p. 89).

According to Bandura (1986) behavior, person factors and environmental variables interact. According to the social interdependence theory (Johnson & Johnson, 2013), positive interdependence will result in promotive interaction. Firstly, promotive interaction was therefore dependent on the strength of positive interdependence – the perception (a person factor) of students that it is necessary for them to rely on and help each other (behavior).

Secondly, promotive interaction was also structured in the environment (paragraph 4.9). These environmental variables targeted students' behavior directly, as well as their perceptions. (a) During the first lecture period, when students were introduced to CPPS and the procedure explained and motivated, the advantage of teamwork was explained and students were made aware of the fact that they would have to cooperate, solve the problems timeously – and were encouraged to do so. (b) During the tutorial, questions from students regarding the problems were answered by involving both partners and facilitating a discussion between the two of them, guiding them towards an answer. It was explained to students that questions from individual students will not be answered. When a student left a partner, and approached the lecturer or assistant to ask a question, the student was accompanied back to his or her partner to involve both students in a discussion. (c) During the CPPS tutorial, groups were monitored to ensure that they cooperated. (d) At University A, when a pair were done, they handed in the paper with their solutions and answers to the problems and were free to go. At University B, this aspect was changed to create another opportunity for promotive interaction. At University B, students used their cell phones to submit their answers on a website. By closing the website timeously, an opportunity was created for the lecturer to discuss the problems, solution strategies, and answers to the problems on the board. This gave students a final opportunity to explain to and seek clarification from each other.

6.2.1.3 Individual accountability and personal responsibility

According to Johnson and Johnson (2013, p. 105) positive interdependence will create "responsibility forces" that will make team members feel more accountable and responsible to complete their part of the work and facilitate the success of other team members. The structuring of positive interdependence was described in paragraph 4.9.

An important environmental variable affecting personal accountability is the group size. One of the goals of using pairs was to make each member's contribution (or lack thereof) easily visible and strengthen the moral imperative to accept responsibility and contribute towards the success of the group. Also, in a classroom environment, especially an auditorium where students cannot sit around a table in groups of more than two, a third (or fourth) person may easily feel excluded, hampering their ability to participate. As described in paragraph 4.9.2, students were not allowed to form their own groups as it would be easier for students, so inclined, to cut corners and to not contribute fully when working with friends.

Students wrote an individual test at the beginning of the tutorial to keep them individually accountable and encourage them to assume responsibility for their own preparation for the tutorial. During the mid-term and end-of-term examinations, students were held individually accountable for the total of their learning activities – albeit to themselves and not to their partners.

6.2.1.4 Social skills

During the development of CPPS (Van Niekerk & Mentz, 2013) it became clear that generally students worked well together in groups of two. To a certain extent this was probably due to the small group size (Johnson et al., 2008, p. 2:5), and the fact that the problems only had a single correct answer, and well defined procedures were used to solve the problems. It was therefore not necessary to debate the merits and choose between a good and a better answer. It was only a matter of right and wrong, which problem-solution strategy was successful and which one was not.

However, it was still decided to give students specific guidelines to help them establish a working relationship with a stranger. These guidelines were given to them during the first lecture, when introducing CPPS and explaining and motivating the procedure. The guidelines focused on forming the group and organizing the activities necessary for the functioning of the group. (Johnson et al., 2008, p. 7:5).

During each tutorial, just after the completion of the individual test, different social skills was introduced and discussed. Because studies showed that more than half of engineering students are more introverted and because introverts may be more uncomfortable working in groups (Felder, Felder, & Dietz, 2002), the first topics discussed during social skills training were related to introversion and extraversion. Conflict resolution, such as learning to speak, learning to listen, and asking outside help to resolve differences, was also discussed.

It was felt that the specific guidelines related to forming a working relationship with a stranger, knowing that there is a slightly better than 50% chance that a partner is also more introverted, and therefore probably also a bit uncomfortable working in a group, and knowing how to resolve conflict, was sufficient to make effective cooperation possible.

6.2.1.5 Group processing

When discussing a new group skill, revision of a previous group skill was done to give students the opportunity to reflect on their own application of those skills. Students were also encouraged to show their excitement and congratulate each other when they succeeded in solving a difficult problem together, celebrating the success of their cooperation.

At University B, after students submitted their solutions on the website, the problem solution strategies and solutions to the problems were discussed. During this time students could also ask questions and suggest alternative ways to solve the problems. The discussion of the solutions and answers gave students an opportunity to reflect on their interaction and the effectiveness of their cooperation, which is another aspect of group processing (Felder & Brent, 2016, p. 247).

A graphical presentation of the CPPS procedure is shown in Figure 6.1. The presentation is based on the theoretical framework developed in paragraph 3.2.

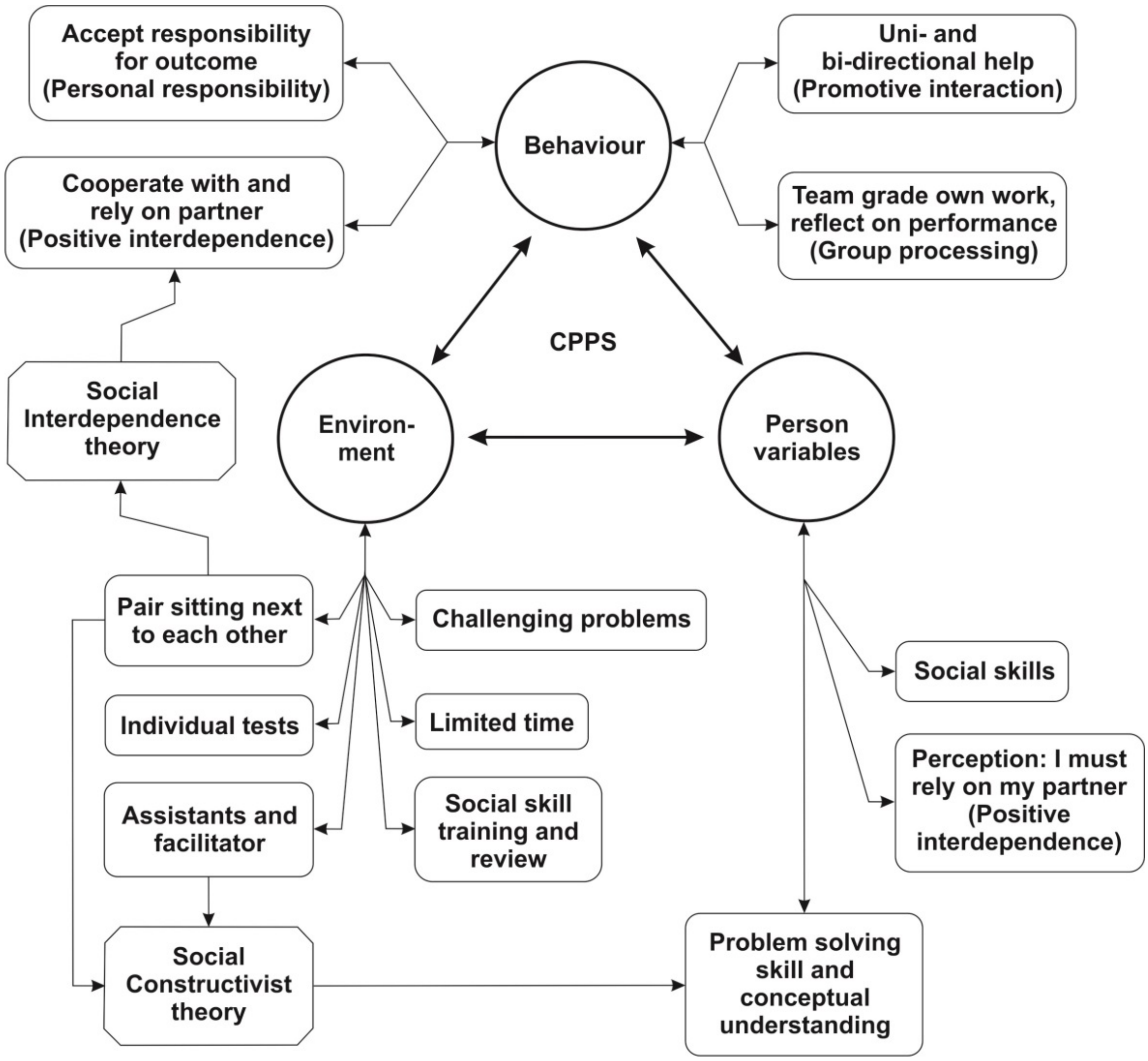

Figure 6.1: The CPPS procedure

6.2.2 An evaluation of the success of the structuring of the five elements of CL in CPPS

The second research subquestion was: How successful was CPPS with regards to the structuring of the five elements of CL?

The second research question was answered using the analysis of qualitative and quantitative data. The qualitative data were obtained from the student interviews, the answers to the open-ended questions in the assistant questionnaires, observer reports, the two open-ended questions in the students' questionnaire and the researcher's journal. The quantitative data were obtained from a Likert-scale student questionnaire. The first element of CL considered, is positive interdependence.

6.2.2.1 Positive interdependence

According to Johnson and Johnson (2013) positive interdependence exists if team members have one (or both) of the following perceptions: (a) That one team member cannot succeed unless the other also succeeds; (b) That they need to coordinate their efforts in order to complete a task. During CPPS, both these aspects played a role but it was clear that the second aspect was the most important and a common occurrence. Several interviewees mentioned how they coordinated their efforts (paragraph 5.2.1.1). The following remark is typical: *I suggested equations that I knew would work, for which I knew the variables and then the other guy said yes, he agrees, or no he has other equations. [B4]* One of the observers (paragraph 5.4.1) wrote: *An explanation by the lecturer of the problem-solution strategy or the solution to the problems was followed by intensive discussion between the members of the group, explaining the work to each other or trying to get clarity of what has been said.* [OB] The student assistants also observed how students challenged each other and *spent a lot of time figuring things out and in so doing gained a lot from each tutorial.* [SA5]. In their answers to the open-ended questions in the student questionnaire (paragraph 5.6 and Figure 5.3), students also described how they learned from each other and how it helped to share their perspectives with each other.

There is sufficient evidence that in general, positive interdependence was successfully structured into the cooperation between most partners during CPPS. However, there were factors that inhibited positive interdependence.

According to the social cognitive theory (Bandura, 1986), there is a reciprocal interaction between behavior, environmental influences and personal factors. With regards to positive interdependence, the structuring of positive interdependence took place in the environment while the perception of the partners that they must coordinate their efforts, is a cognitive or personal factor. As mentioned in paragraph 6.2.1.1, the structuring of positive interdependence during CPPS was such that this perception was neither inevitable nor automatic. The students still had to take the decision to coordinate their efforts with their partners and they had to accept the responsibility to make their interaction successful. It is clear from the results that there were instances where positive interdependence was hampered or even absent due to one partner's decision not to cooperate.

Also, during the interviews, a few instances were mentioned where positive interdependence did suffer due to a large difference in ability or preparation between the partners (paragraph 5.2.1.1). In that sense the success (or in this case, lack of success) of one partner affected the success of the other partner.

There was a difference is the procedure followed at the two universities that seemed to have influenced positive interdependence.

At University A, attendance of tutorials was compulsory and a few isolated cases were reported where students did not cooperate with their partners. At University B, attendance of the tutorials was voluntary and that seemed to lead to better cooperation between students. An interviewee said: *[All] students who attended, wanted to work. [B9]* In contrast to University A, no mention was made by any interviewee from University B of students not wanting to cooperate with their partners. The quantitative data from the Likert scale questionnaire also indicated that students at University B essentially agreed that positive interdependence existed (2.82 out of a maximum of 4) while the average at University A was significantly lower at 2.34 (paragraph 5.7.2).

A decision to cooperate, combined with the favorable environmental factors, resulted in a specific behavior, promotive interaction, which will now be discussed and analyzed.

6.2.2.2 Promotive interaction

As discussed in paragraph 3.3.1.2, promotive interaction is characterized by students helping each other to achieve the group's goals. It seems clear that promotive Interaction was sufficiently structured into the procedure.

The results of the Likert-scale questionnaire (paragraph 5.7.1) indicated that students at both universities agreed that promotive interaction did take place during CPPS. The average for the factor promotive interaction at both universities was 3 (agree) out of a maximum of 4 (strongly agree).

In the student questionnaire, when asked what it was that they have learned because of CPPS, more than 68% of students at University A and 61% of students at University B, answered that CPPS facilitated their learning (paragraph 5.6 and Figure 5.3).

Promotive interaction took two forms: bi-directional help, where the two students helped each other and their understanding augmented each other, and uni-directional help where one student received help from a peer or an assistant or the lecturer. Bi-directional and uni-directional help are explained by the social constructive theory of learning and will now be discussed.

6.2.2.2.1 Bi-directional help

Bi-directional help fits in well with the cooperation facet of social constructivist theory of learning (paragraph 3.2.3). One aspect of cooperation is that it gives rise to socio-cognitive conflict.

A student assistant (paragraph 5.3.2) described how two “good” students who seemed to be on the same level, often challenged each other’s understanding and reasoning and asked meaningful questions – often beyond the scope of the work. Interviewees also mentioned how they shared different perspectives and compared their reasoning and answers.

A second facet of cooperation is the creation of a bi-directional zone of proximate development. An observer (paragraph 5.4.1) noted how an explanation on the board by the lecturer, was followed by intense discussion between the two students explaining the work or trying to get clarity on what has been said. More than two thirds of the interviewees (paragraph 5.2.1.2) mentioned how their understanding complemented each other and how they planned the solution strategy together and compensated for gaps in each other’s knowledge and understanding (Figure 5.2).

6.2.2.2.2 Uni-directional help

Uni-directional help correlates well with the second facet of socio-constructivist learning, enculturation, where a more skilled individual provides guidance (paragraph 3.2.3).

Uni-directional help took three forms. Primarily it took the form of a student who had a better understanding; explaining something to a partner who did not understand that aspect as well as the explaining partner did. Student assistants also provided help when the two individuals in the team reached a dead end. When it became clear that several groups experienced problems with a concept the lecturer or facilitator explained on the board.

Two aspects seemed to have inhibited promotive interaction. Promotive interaction was affected by the extent to which one partner felt responsible for the other partner. Generally, it seemed that students were willing to provide help, but it was not always the case. An interviewee said: *It also depends on the bright guy’s personality. If he wants to help you or if he wants just to finish the tutorial and leave.* [A2]

Also, when the difference in ability or preparedness, or both, became too large, is seems one student tended to dominate the interaction. An unequal contribution by partners was reported by some students at both universities (paragraph 5.6): *Sometimes it felt as if I did all the work. It was solved by giving my partner something to do even if it was only doing calculations on the pocket calculator.*

6.2.2.3 Personal responsibility and individual accountability

Environmental factors were manipulated to strengthen feelings of individual accountability and personal responsibility. The results seems to corroborate the remark by Johnson and Johnson

(2013) that keeping the group small increases the team members' feeling of accountability. An interviewee remarked: *I spent almost the whole weekend preparing for Thermodynamics in order not to be a liability to the other student.* [A3]

Another environmental factor was working with strangers, which seemed to have increased students' focus on the work. An interviewee remarked that when working with strangers: *You've got nothing to get social about.* [A2] A student assistant remarked: *The quality of the tutorials degenerated as students continued to sit in their friendship groups and correspondingly spent less time actually working and more time chatting.* [SA5] This is in agreement with the experience of Oakley et al. (2004) that students who know each other and are so inclined, are more prone to taking shortcuts. The implication is that when working together, two strangers should be more conscientious than two friends.

To encourage students to come prepared, students wrote an individual test. At University A, the marks obtained in this test contributed to the participation mark and while many students would have preferred to write the test after they have done the problems it seemed that generally students indeed studied for the test (paragraph 5.2.1.3). At University B, bonus points were awarded for the tutorial and that made it easier for students to attend to other priorities. An interviewee remarked: *I think because it is a bonus 5% many people wrote off the tutorial if they became busy. Because it is only a bonus while in the other subject you will actually lose marks.* [B8].

Attendance of tutorials at University B was voluntary. This seems to have had a positive effect on students feeling of responsibility. An interviewee remarked: *Students who attended wanted to work.* [B9] The results of the Likert-scale questionnaire (paragraph 5.7.1) indicated that students at both universities accepted responsibility with an average of 2.84 for University A and 2.99 for University B.

Despite the differences between the two universities, it seems that personal accountability and personal responsibility was sufficiently structured into the procedure at both universities.

6.2.2.4 Group work skills

It seems that students could work together most of the time without conflict. One statement in the Likert-scale student questionnaire was, "Conflict regularly occurred during CPPS".

The average at both universities was a very low 1.55 which places it between "disagree" and "strongly disagree".

One of the student assistants remarked: *There was a large measure of goodwill and cooperation in the groups.* [SA6] An observer wrote: *The students' group work skills are really good .... most worked amazingly well together* [OA]

The student assistants and lecturer played an important role in conflict resolution: *When he thinks he is right and I think I am right then it is very simple, we raise our hands and ask the lecturer: Is this right or that? And so you sort it out.* [B3]

Some interviewees did mention having trouble establishing a working relationship. In response to the question in the student questionnaire, "What problems did you experience?" 21% of the respondents at University A (paragraph 5.6.1.2) and 33% of the respondents at University B (paragraph 5.6.2.2), reported ineffective or problematic cooperation during what seemed isolated incidents. Also, it seems that this was more due to the absence of a sufficiently strong enough feeling of positive interdependence than poor interpersonal skills: *The other guy only trusted his own skills, whether it was right or wrong.*

The last element of the five elements of CL is group processing.

6.2.2.5 Group processing

During the discussion of group work skills, a review of group work skills discussed previously was done to give students an opportunity to reflect on their own implementation of those skills. Also at University B, after submitting their answers on the website, the solution to the problems were discussed giving students the opportunity to reflect on their approach to the problem and their interaction. The success of this approach is inferred from remarks by students.

Students did reflect on their group work skills. A few interviewees mentioned how they applied the skill "forming" explained during the first lecture, to establish a working relationship with a stranger: *Just hear what is his name, where does he stay, get comfortable with each other...* [B6]

Another mentioned that the awkwardness between him and his partner disappeared once they started working and focused on the task: *It is initially a bit awkward to meet the person. Once you start working, you focus on the work.* [A3]

Several said that as the semester progressed, they got used to working with strangers. *Initially when we heard how it is going to work, it was a bit strange but later we got used to it and it improves you people skills.* [B6]

In conclusion, strong evidence of the structuring of the five elements of CL emerged from the different data sources. In general students, coordinated their efforts, gave, and received help, reflected on their own group work skills, and cooperated without conflict.

Apart from the structuring of the five elements of CL, the students and other role players had often strong views and opinions about CPPS which are discussed in the next paragraph.

6.2.3 Different perceptions of CPPS

The third research subquestion is: What are the different role players' perceptions of CPPS?

6.2.3.1 CPPS creates an effective teaching-learning environment

All role players were positive about this aspect of CPPS. It is evident that students experienced promotive interaction as discussed in the previous paragraph (paragraph 6.2.2.2). In summary, the average for the promotive interaction factor in the Likert-scale questionnaire at both universities were 3, almost two thirds of the students answering the open-ended question in the student questionnaire said that CPPS facilitated their learning. Many interviewees mentioned how they helped each other and received help.

Except for one student assistant who felt CPPS would be better for projects, the other nine were positive. One wrote: *In my opinion a fantastic idea.* [SA9] They noted that, instead of the usual chatting and socializing, students focused on the work and helped each other (paragraph 5.3.2).

For me, an important advantage of CPPS was that it took a huge teaching load off the shoulders of the instructor. It was no longer necessary for the instructor to explain often trivial detail to individual students. A lot of explaining took place between students. When they got stuck they could ask an assistant and if it became clear that several groups had problems with the same aspect, the instructor explained to the whole class. CPPS made it possible for the instructor to truly become a facilitator of the learning process (paragraph 5.5.2.).

6.2.3.2 CPPS is well worth the effort

Several researchers reported that the implementation of CL requires more effort (paragraph 1.1). That is also the case with CPPS, but that was a small price to pay for the advantages CPPS had to offer.

Apart from creating an effective learning environment as described in paragraph 6.2.3.1, the atmosphere in class was also better. Felder and Silverman (1988, p. 674) wrote: "Professors, confronted by low test grades, unresponsive or hostile classes, poor attendance and dropouts, know something is not working." As discussed in Chapter 1, prior to CPPS the perception that the teaching strategy used at that stage was not effective was in many respects true for Thermodynamics as well. CPPS changed that. At University A, the lecturer who has been responsible for presenting Thermodynamics for many years wrote: *I perceived a much more positive approach to the subject as a whole. They must have understood the Thermo much better and that in my opinion contributed to the more cheerful atmosphere in the class.* [SA1] At University B the attendance of tutorials increased from a handful of students attending tutorials to an average of 66% of all the students enrolled, attending tutorials (paragraph 5.8.4.1).

Despite the more positive atmosphere in class, some students had reservations about certain aspects of CPPS.

6.2.3.3 Students had mixed feelings about CPPS

It is clear from the discussion so far that there were positive aspects to CPPS. It created an effective teaching-learning environment where generally students experienced promotive interaction and could cooperate amicably. Some interviewees were very positive: *I actually liked it very, very much.* [B3] others were not: *It put me under a lot of stress and I did not enjoy Mondays at all.* [A3] The (voluntary) attendance of tutorials at University B increased from a handful of students to 66% of all enrolled students attending CPPS tutorials (paragraph 5.8.4.1). Yet, in response to the statement in the student questionnaire, *I would like to work like this again in a next subject*, the average for University A was 2.2 and for University B 2.4. This response was unexpectedly low seen in the light of the positive aspects of CPPS.

It seemed that the most common complaint by students was that they could not choose their own partners. There were different reasons for students' resistance towards working with strangers (paragraph 5.3.1). Some students said that they were already part of a group that always work together during tutorials in other subjects and therefore did not like the fact that they could not choose their own partners during CPPS – a reasonable objection. Some students were strong introverts and would have preferred to work alone.

In other subject tutorials, it seems feeding off better prepared, more conscientious students was commonplace. This practise would have been more difficult when working with a stranger during CPPS. According to Felder and Brent (2016) students tend to resist procedures where it is expected of them to take responsibility for their own learning.

In the first contact with the students the random allocation of partners was motivated. This was not sufficient to persuade them to sit at their allocated places. At the first implementation of CPPS at University A, it quickly became clear that resistance to the random allocation of partners was much stronger than anticipated and that the seat allocation procedure used at that stage was not effective. This emphasized the importance of a proper seat allocation procedure which will now be discussed.

6.2.3.4 A traceable seat allocation procedure is vital

At University A, when students entered class, they received a piece of paper with a seat number. It was not possible to check whether students sat at their allocated places and an increasing number of students sat with friends. This had a negative impact on positive interdependence and promotive interaction (paragraph 5.3.2), as well as being an inconvenience to students who wanted to sit at their allocated places now occupied by someone else. The instructor and assistants had the unpleasant task to try to detect and confront (often resentful) students who did not sit at their allocated places. Despite their best efforts and adapting the seat allocating procedure, there were still students who formed their own groups. For large groups, this approach to seat allocation is not satisfactory.

At University B, a laptop with a student card reader was used to allocate seats and record the allocated seat in a spreadsheet. This made it possible to identify and take steps against students who did not sit at their allocated seats and once students realized that, they seemed to accept the arrangement. For me this was a key aspect in the successful implementation of CPPS. If I was not able to ensure that students sat at their allocated places, I do not think I would have continued with the implementation of CPPS.

The last aspect concerning the success of CPPS is to consider its success as teaching-learning strategy. Two aspects are considered: academic achievement and conceptual understanding.

6.2.4 Academic achievement

The fourth research subquestion was: What is the effect of CPPS on the academic achievement of students?

There was no significant difference in the academic performance of the year groups prior to the implementation of CPPS (2012-year groups) and the academic performance of the 2013-year groups who were exposed to CPPS. This result was perhaps to be expected as there were several differences between the 2012 and 2013 groups that could not be controlled.

It was therefore decided to engage in a further investigation of the effect that the number of tutorials students attended had on their final marks. This could be done at University B as CPPS was now implemented every year during Thermodynamics tutorials and data were available for the years 2013 to 2016. It was found that for 2016, the number of tutorials attended had a significant effect on the final marks of the students. However, for the other years (2013-2015), the difference in final marks for students attending a different number of tutorials was not statistically significant (paragraph 5.8.3).

The final marks were a combination of a participation marks and the end-of-term examination marks. Eighty five percent of the participation mark consisted of the scores obtained in three tests taken during the semester. It seemed reasonable to expect that CPPS would have had a more pronounced effect on the test scores than on the examination scores. It was found that for 2013, 2014 and 2015, attending four or more tutorials had a strong to moderately positive effect on the participation marks of students compared to students who only attended two or three tutorials (paragraph 5.8.4).

6.2.5 Understanding thermodynamic concepts

The fifth research subquestion was: What is the effect of CPPS on the students' understanding of thermodynamic concepts?

The relationship between conceptual understanding and problem solving was investigated in paragraph 2.5. It is common in Thermodynamics textbooks to use fundamental concepts as basis of or departure point for the derivation of equations and formulas that is used to solve problems. After the derivation of the equation or formula, the focus shifts to the application of these formulas with conceptual understanding moving to be background.

According to Johnson et al. (2008, p. 1:6) students taught cooperatively, displayed "better high-level reasoning skills". Coştu (2007) also contended that to solve problems with four or more solution steps, require conceptual understanding. It was therefore decided to determine whether CPPS with its challenging problems, would influence the conceptual understanding of the students.

For University B, it was found that there was no significant difference in the conceptual understanding between the 2012-control group and the 2013-experimental group, while at University A there was a decrease in conceptual understanding with a small to medium effect size. According to Felder and Brent (2016), in order to improve students' conceptual understanding, they should be specifically taught the concepts, and their conceptual understanding should be assessed as well. If this is not done, students will not try to understand and master the concepts. The result of this section of the study therefore confirms Felder's advice only to the extent that if concepts are not taught and assessed, conceptual understanding will not improve.

However, this study indicated that attending CPPS tutorials led to better academic performance. Case and Marshall (2004), observed that the approach that students adopt during problem solving can vary between a surface procedural approach and a deep procedural approach. In other words, during a deep procedural approach, students develop the procedural skills necessary to solve the problems without necessarily improving their conceptual understanding. It is possible that the improvement in academic performance of students attending CPPS tutorials was predominantly due to a shift towards a deeper procedural approach.

6.2.6 The primary research question

The primary research question was: How can a cooperative pair problem solving strategy (CPPS) be designed for Mechanical Engineering Thermodynamics tutorials and how successful is its implementation? The question was answered by describing how the elements of CL were structured into a procedure based on pair programming and pair problem solving where students worked together in groups of two. Furthermore, the results indicated that the five elements of CL were sufficiently structured in the procedure. CPPS also created an effective teaching-learning environment and dramatically reduced the teaching load on the lecturer. CPPS had no significant effect on the conceptual understanding of the students, but attending the tutorials improved their academic performance. Although students had mixed feelings about CPPS, role players were generally positive about CPPS and I, the lecturer is convinced that CPPS is well worth the effort.

6.3 Additional remarks

It is necessary to deal in a firm but understanding way with students' resistance towards working with strangers. Working with a stranger as a pair is most probably a radical departure from what students are used to.

Introverted (and shy) students may need some time to get used to the arrangement. Conscientious students who are already part of a group (of friends) with the same work ethic may also prefer to continue to work with those friends. These are all reasonable objections to having to work with strangers. It is perhaps best to deal with this resistance by exposing students to CPPS as early as the first semester of their first year of study when they may possibly be more susceptible to new ideas. CPPS should then also be implemented in subsequent semesters.

To deal with the initial resistance towards working with strangers it is necessary to explain the rationale behind the random allocation of partners to the students as well as provide training in group work skills. However, the most important aspect is to use a seat allocation system that makes it possible to track which students did not sit in their allocated seats. It seems once students realize they cannot cheat the system most will accept the arrangement.

Attendance of tutorials at University A was compulsory while at University B it was voluntary. Giving students the choice to attend or not, may have the result that the students who do attend are more motivated. It may also be better, according to the principles of self-directed learning, to allow the student to choose whether to attend or not. However, leaving the student the choice may result in some students missing an effective learning opportunity, as well as the opportunity to develop their social skills just because they do not like CPPS for a trivial reason.

On the other hand, compulsory attendance may lead to resentment in some students. Compulsory attendance also requires additional administration as records must be kept of students who presented valid excuses for not being able to attend. The best solution may be to expect from students to attend a certain percentage of tutorials during their first exposure to CPPS, but allow more freedom later on.

It seems justified to conclude that attending CPPS tutorials does result in better academic performance. However, to better quantify the effect, it would be necessary to conduct a test where the different variables can be controlled more effectively. This may be easier said than done. To begin with, it may be difficult to justify dividing students of the same year group into a control and experimental group given the clear advantages of CPPS. Furthermore, Ten Cate (2001) argues that academic performance is primarily dependent on the effort made by students, and that students adapt their efforts according to the efficiency of the teaching strategy. A better teaching strategy may therefore result in students putting in less effort into their preparation for tests and examinations, reducing the effect of the teaching strategy on their academic performance.

6.4 Limitations of the study

Because there were differences between the universities, the results obtained at the two universities could not be compared. Nevertheless, valuable results were obtained from the implementation at both universities increasing the possibility that it will also be successful at other universities.

Apart from differences that can normally be expected between any two universities – such as differences in student culture and attitude, and possible differences in prior exposure and experience with group work, there were other differences, which could also not be controlled. Although the courses at both universities were the first introductory course in Thermodynamics, the curriculums were not identical and provision had to be made for established procedures and practices at the two universities. At University A, the tutorials in all subjects follow the same procedure. CPPS deviated in several respects from this procedure, which caused resentment in some students. This may have had a negative effect on students' cooperation and perception of CPPS.

Another difference between the two universities was the seat allocation procedure. When it became clear that the seat allocation procedure at University A was ineffective it was adjusted in order to be more effective. Despite the adjustment some students still sat with friends. An effective seat allocation procedure was developed and implemented at University B. The initial problems with the seat allocation procedure at University A had an unexpected advantage. It made it possible to observe the detrimental effect on positive interdependence and promotive interaction of students sitting with friends and provided the motivation for the development of a better procedure.

However, the fact that CPPS could be implemented successfully at two different universities gave an indication of the repeatability and robustness of CPPS.

6.5 Topics for further research

6.5.1 Studying the effect of early and continued exposure to CPPS

As discussed in paragraph 5.7.1.1, an unexpectedly high percentage of students indicated that they would not like "to work like this [CPPS] again in a next subject". The students in this study was in their first semester (University A) and second semester (University B) of their second academic year of study with several students repeating Thermodynamics, and probably other subjects as well. The implication is that for those students, it was already their third year on campus.

There could be several reasons for this high percentage of students who disapproved of CPPS. Apart from having to work with strangers, the reason could also well be that the students are not used to CL, or have had bad experiences with group work. Perhaps they resorted to often unsuitable strategies in the past, such as feeding off stronger or better prepared students during tutorials.

Exposing students to CPPS early in their study careers when they may be more susceptible to new ideas might result in students more readily accepting the random allocation of partners during CPPS, improve their social skills, and increase the likely benefit of the procedure when applied in subsequent semesters.

6.5.2 Improving conceptual understanding

Even though conceptual understanding as such is not assessed in Thermodynamics, it is important that students develop a proper understanding of thermodynamic concepts while attending Thermodynamics as conceptual understanding is necessary in follow-on courses and to solve ill-structured problems as engineer. Therefore, it should be investigated how to combine the teaching and learning of conceptual understanding with problem solving. The first step should be to confirm whether the improvement in academic performance in this study was mainly due to a deeper procedural approach (Case & Marshall, 2004), and if so, how CPPS can also aid in the teaching and learning of conceptual understanding.

Another aspect of conceptual understanding is the possible difference between “fundamental concepts” and “operational concepts”. Fundamental concepts are often formulated in words, and used as the starting point in the derivation of equations (Felder & Brent, 2016, p. 161). Operational concepts can be represented by symbols; usually have numerical values, and are used in equations and formulas. The second step should therefore be to investigate the existence of such a difference, and if so, to determine the possible effect on teaching and learning of conceptual understanding.

6.5.3 Incorporating CPPS into distance learning

At the end of 2016, residential tertiary education in South Africa was seriously disrupted and initiatives to enable students to study off-campus are currently receiving a lot of attention. It should be investigated whether web-based, face-to-face technology can be used for the conduction of CPPS type tutorials.

6.6 Contribution of the study

CPPS is a well-structured, easy-to-implement, cooperative teaching-learning strategy suitable even for large (>100) groups in engineering science problem-solving tutorials where students work amicably together. CPPS will most probably also be suitable for problem solving tutorials in the pure sciences.

With regards to teaching and learning, CPPS creates an effective teaching-learning environment that (a) dramatically reduces the teaching load on the instructor’s shoulders (especially in large classes) and creates an effective teaching-learning environment due to active learning and peer instruction; (b) results in a much more positive and cheerful atmosphere in class, and (c) improves students’ academic performance. These advantages make the implementation of CPPS well worth the effort.

Using a laptop and student card reader for group formation during implementation eliminates the unpleasant task (for the facilitator) of trying to detect and confront often resentful students for not adhering to the seating arrangement. Once students realized they cannot cheat the system, they willingly seem to accept the group-formation procedure. As the semester progressed, many students got used to working with strangers and even welcomed the opportunity to meet new people and improve their group work skills.

6.7 Summary

This study was conducted to find a solution to the (often) poor pass rates in the first introductory thermodynamics course and the perception of students that Thermodynamics is difficult to understand and pass. Using pair programming and pair problem solving as departure points, a procedure, CPPS, was developed that incorporated the five elements of cooperative learning.

A theoretical framework for CPPS was developed that incorporate three theories. The framework is based on the social cognitive theory of Albert Bandura (1986), which has been applied extensively in the study of teaching and learning. The three interacting factors in this research are working together (behavior), the student (cognition and other personal factors), and the group and other environmental influences. Two theories that was used in the context of students working together to inform the social cognitive theory are the social interdependence theory and the social constructivist theory. Johnson and Johnson (2013) state that the social interdependence theory is the most important theory dealing with cooperation, and identified five elements necessary for effective cooperation. The social constructivist theory gives a description of how learning takes place in a social environment.

The empirical research was conducted using a pragmatic approach and a convergent parallel mixed methods design, a quasi-experiment, and a correlational analysis. The emphasis was on qualitative methods relying on student interviews, six open-ended questions in a student assistant questionnaire, observer reports, a researcher’s journal, and two open-ended questions in a student questionnaire. The quantitative measurements included a Likert-scale questionnaire completed by students before and after their exposure to CPPS, a quasi-experiment to determine the effect of CPPS on academic performance and conceptual understanding, as well as a correlational analysis (using four year’s data) to determine the effect the number of tutorials attended had on academic performance.

It was found that the five elements of cooperative learning could be successfully structured in CPPS. It was easy to implement especially due to the use of laptop-based technology for group formation. Attendance of CPPS tutorials had no effect on students’ conceptual understanding, confirming the literature, which stated that conceptual understanding must specifically be taught and assessed. Generally, students were positive about the procedure, although some disliked specific aspects, such as the fact that they could not choose their own partners. CPPS created an effective teaching-learning environment that dramatically reduced the teaching load of the instructor. Attending CPPS tutorials also improved students' academic performance.

REFERENCES

Ahern, A. (2007). What are the perceptions of lecturers towards using cooperative learning in civil engineering? *European Journal of Engineering Education, 32*(5), 517-526.

American Accreditation Board for Engineering Teaching (ABET). (2013). Criteria for accrediting engineering programs 2014-215. Retrieved from http://www.abet.org/wp-content/uploads/2015/04/E001-14-15-EAC-Criteria.pdf

Bächtold, M. (2013). What do students "construct" according to constructivism in science education? *Research in Science Education, 43*(6), 2477-2496. doi:10.1007/s11165-013-9369-7

Baeten, M., Kyndt, E., Struyven, K., & Dochy, F. (2010). Using student-centred learning environments to stimulate deep approaches to learning: Factors encouraging or discouraging their effectiveness. *Educational Research Review, 5*(3), 243-260. doi:10.1016/j.edurev.2010.06.001

Baker, D., Ezekoye, O., Schmidt, P., Jones, C., & Liu, M. (2000). *ThermoNet: A web-based learning resource for engineering thermodynamics.* Paper presented at the 2000 ASEE Annual Conference, Tampere, Finland.

Baker, T., & Clark, J. (2010). Cooperative learning – a double edged sword: A cooperative learning model for use with diverse student groups. *Intercultural Education, 21*(3), 257-268.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory.* Englewood Cliffs, NJ: Prentice-Hall.

Barkley, E. F., Cross, K. P., & Major, C. M. (2005). *Collaborative learning techniques: A handbook for college faculty.* (1st ed.). San Francisco: Jossey-Bass.

Baviskar, S. N., Todd Hartle, R., & Whitney, T. (2009). Essential criteria to characterize constructivist teaching: Derived from a review of the literature and applied to five constructivist-teaching method articles. *International Journal of Science Education, 31*(4), 541-550. doi:10.1080/09500690701731121

Becerra-Labra, C., Gras-Martí, A., & Torregrosa, J. M. (2011). Effects of a problem-based structure of physics contents on conceptual learning and the ability to solve problems. *International Journal of Science Education, 34*(8), 1235-1253. doi:10.1080/09500693.2011.619210

Bell, B. S., & Kozlowski, S. W. J. (2008). Active learning: Effects of core training design elements on self-regulatory processes, learning, and adaptability. *Journal of Applied Psychology, 93*(2): 296-316.

Bell, B. S., & Kozlowski, S. W. J. (2009). Toward a theory of learner-centered training design: An integrative framework of active learning [Electronic version]. In S. W. J. Kozlowski & E. Salas (Eds.), *Learning, training, and development in organizations* (pp. 263-300). New York, Routledge.

Bernard, H. R., & Ryan, G. W. (2010). *Analyzing qualitative data.* California: SAGE.

Bilgin, I. (2006). The effects of pair problem solving technique incorporating Polya's problem-solving strategy on undergraduate students' performance in Chemistry. *Journal of Science Education, 7*, 101-106.

Blicblau, A. S., & Van der Walt, H. (2008). *Strategies for progressing through engineering.* Paper presented at the SEFI 36th Annual Conference, Aalborg, Denmark.

Borgnakke, C. (2014). *Fundamentals of thermodynamics.* (8th ed.). Hoboken, NJ: John Wiley & Sons.

Borgnakke, C., & Sonntag, R. E. (2009). *Fundamentals of thermodynamics* (7th ed.). Hoboken, NJ: John Wiley & Sons.

Boud, D., Cohen, R., & Sampson, J. (Eds.). (2014). Peer learning in higher education: Learning from and with each other. New York: Routledge.

Brooks, B., & Koretsky, M. (2010). *The effect of peer instruction on students' construction of conceptual understanding in Thermodynamics.* Paper presented at the American Society for Engineering Education, Louisville, Kentucky.

Bryman, A. (2012). *Social research methods* (4th ed.). New York: Oxford University Press.

Case, J., & Marshall, D. (2004). Between deep and surface: Procedural approaches to learning in engineering education contexts. *Studies in Higher Education, 29*(5), 605-615. doi:10.1080/0307507042000261571

Castellanos, M., & Enzer, J. (2013). *Promoting metacognition through reflection exercises in a Thermodynamics course*. Paper presented at the 120th ASEE Annual Conference and Exposition, Atlanta, Georgia.

Cengel, Y. A., & Boles, M. A. (2007). *Thermodynamics: An engineering approach* (6th ed.). New York: McGraw-Hill.

Cengel, Y. A., Boles, M. A., & Kanoglu, M. (2011). *Thermodynamics: An engineering approach* (7th ed.). New York: McGraw-Hill.

Ceylan, T. (2012). *Challenges of engineering Thermodynamics education*. Paper presented at the Illinois-Indiana ASEE Sectional Conference, Valparaiso, Indiana.

Channel, D. F. (2009). The emergence of the engineering sciences: An historical analysis. In A. Meijers (Ed.), *Handbook of the philosophy of science: Philosophy of technology and engineering sciences* (Vol. 9, part I). Amsterdam: North Holland.

Clark, L.A., & Watson, D. (1995). Constructing validity: Basic issues in objective scale development. *Psychological Assessment*, (7)3, 309-319.

Cobb, P. (1996). Where is the mind? A coordination of sociocultural and cognitive constructivist perspectives. In C. T. Fosnot (Ed.), *Constructivism: Theory, perspectives, and practice (pp. 39)*. New York, NY: Teachers College Press.

Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design research: Theoretical and methodological issues. *Journal of the Learning Sciences, 13*(1), 15-42.

Comer, K. (2009). The ethics of conducting educational research on your own students. *Journal of Nursing Law*, (13)4, 100-105.

Coştu, B. (2007). Comparison of students' performance on algorithmic, conceptual, and graphical chemistry gas problems. *Journal of Science Education and Technology, 16*(5), 379-386. doi:10.1007/s10956-007-9069-z

Cracolice, M. S., Deming, J. C., & Ehlert, B. (2008). Concept learning versus problem solving: A cognitive difference. *Journal of Chemical Education, 85*(6), 873-878.

Creswell, J. W. (2008). *Educational research: Planning, conducting and evaluating quantitative and qualitative research* (3rd ed.). Boston, MA: Pearson.

Creswell, J. W. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches* (3rd ed.). Thousand Oaks, California: SAGE.

Creswell, J. W. (2014a). *Educational research: planning, conducting, and evaluating quantitative and qualitative research* (4th ed.). Harlow, Essex: Pearson.

Creswell, J. W. (2014b). *Research design: qualitative, quantitative, and mixed methods approaches* (4th ed.). Thousand Oaks, California: SAGE.

CSLP. (1998). *cooperative learning Implementation Questionnaire*. Retrieved from https://www.concordia.ca/content/dam/artsci/research/cslp/docs/cliq.pdf

Detloff, H. (2000). *Experiments in cooperative learning: Successes of an engineering novice.* Paper presented at the 30th ASEE/IEEE Frontiers in Education Conference, Kansas City, USA.

Dickson, L. (2010). Race and gender differences in college major choice. *Annals of the American Academy of Political and Social Science, 627*(1), 108-124. doi:10.1177/0002716209348747

Docktor, J. L., Strand, N. E., Mestre, J. P., Ross, B. H., Singh, C., Sabella, M., & Rebello, S. (2010). *A conceptual approach to physics problem solving.* Paper presented at the AIP Conference.

Driver, R., Asoko, H., Leach, J., Scott, P., & Mortimer, E. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*(7), 5-12.

ECSA (Engineering Council of South Africa). (2012). E-01-P. Background to accreditation of engineering education programmes (Rev. 2nd ed.). 22 November 2012: Engineering Council of South Africa.

ECSA (Engineering Council of South Africa. (2014). E-02-PE Qualification Standard for Bachelor of Science in Engineering/Bachelors of Engineering. Retrieved from https://www.ecsa.co.za/education/EducationDocs/E-02-PE_Whole_Qualification_Standard_r4.pdf

Ertmer, P. A., & Newby, T. J. (2013). Behaviorism, cognitivism, constructivism: Comparing critical features from an instructional design perspective. *Performance Improvement Quarterly, 6*(4), 50-72.

Felder, R. M. (2007). Sermons for grumpy campers. *Chemical Engineering Education, 41*(3), 183.

Felder, R. M., & Brent, R. (1994). *Cooperative learning in technical courses: Procedures, pitfalls, and payoffs*. Retrieved from https://eric.ed.gov/?id=ED377038

Felder, R. M., & Brent, R. (2003). Learning by doing. *Chemical Engineering Education, 37*(4), 282-283.

Felder, R. M., & Brent, R. (2009). Active learning: An introduction. *ASQ Higher Education Brief, 2*(4), 1-5.

Felder, R. M., & Brent, R. (2016). *Teaching and learning STEM: A practical guide.* San Francisco: Jossey-Bass.

Felder, R. M., Felder, G. N., & Dietz, E. J. (2002). The effects of personality type on engineering student performance and attitudes. *Journal of Engineering Education, 91*(1), 3-17.

Felder, R. M., & Silverman, L. K. (1988). Learning and teaching styles in engineering education. *Engineering Education, 78*(7), 674-681.

Felder, R. M., Woods, D. R., Stice, J. E., & Rugarcia, A. (2000). The future of engineering education II. Teaching methods that work. *Chemical Engineering Education, 34*(1), 26-39.

Field, A. P. (2013). *Discovering statistics using IBM SPSS statistics* (4th ed.). Los Angeles: Sage.

Foley, A. (2007). *Escape from Carnot: A new way to introduce the mysterious property, entropy.* Paper presented at the Annual Conference and Exposition of the American Society for Engineering Education, Honolulu, Hawaii.

Forman, E. (1989). The role of peer interaction in the social construction of mathematical knowledge. *International Journal of Educational Research, 13*(1), 55-70. doi:10.1016/0883-0355(89)90016-5

Fraser, D. M. (1993). Collaborative study groups: A Learning Aid in Chemical Engineering. *Chemical Engineering Education*, 27, 38-64.

Fredericks, A. C., Fleming, L. N., Burrell, J. O., & Griffin, A. R. (2012). *Perspectives on the learning environment: Classroom culture and social transactions at an HBCU.* Paper presented at the ASEE Annual Conference and Exposition, San Antonio, Texas.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). *Active learning increases student performance in science, engineering, and mathematics*. In *Proceedings of the National Academy of Sciences of the United States of America, 111*(23), 8410-8415. doi:10.1073/pnas.1319030111

Froyd, J. (2010). *Positive interdependence, individual accountability, promotive interaction: Three pillars of cooperative learning*. Retrieved from http://www.foundationcoalition.org

Gaigher, E., Rogan, J. M., & Braun, M. W. H. (2007). Exploring the development of conceptual understanding through structured problem-solving in Physics. *International Journal of Science Education, 29*(9), 1089-1110.

Gilmore, R. (2008). *The structure of Thermodynamics*. Retrieved from www.physics.drexel.edu/~bob/Chapters/thermo_04.pdf

Giustini, D. (2014). Utilizing learning theories in the digital age: From theory to practice. *Journal of the Canadian Health Libraries Association/Journal de l'Association des bibliothèques de la santé du Canada, 30*(1), 19-25.

Gok, T. (2014). Peer instruction in the Physics class room: Effects on gender difference performance, conceptual learning, and problem solving. *Journal of Baltic Science Education, 13*(6).

Goos, M., Galbraith, P., & Renshaw, P. (2002). Socially mediated metacognition: Creating collaborative zones of proximal development in small group problem solving. *Educational Studies in Mathematics, 49*(2), 193-223.

Grabinger, S., Aplin, C., & Ponnappa-Brenner, G. (2007). Instructional design for sociocultural learning environments. *E-Journal of Instructional Science and Technology, 10*(1), n1.

Guest, G., Bunce, A., & Johnson, L. (2006). How many interviews are enough? An experiment with data saturation and variability. *Field Methods, 18*(1), 59-82. doi:10.1177/1525822x05279903

Gultepe, N., Yalcin, C. A., & Kilic, Z. (2013). Exploring effects of high school students' mathematical processing skills and conceptual understanding of chemical concepts on algorithmic problem solving. *Australian Journal of Teacher Education, 38*(10).

Halloun, I. A., & Hestenes, D. (1985). The initial knowledge state of college physics students. *American Journal of Physics, 53*(11), 1043-1055.

Hansson, S. O. (2007). What is technological science? *Studies In History and Philosophy of Science, 38*, 523-527.

Hansson, S. O. (2009). Risk and safety in technology. In A. Meijers (Ed.), *Philosophy of Technology and Engineering Sciences* (1st ed., pp. 1069-1102). Amsterdam: North Holland.

Heller, P., & Hollabaugh, M. (1992). Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups. *American Journal of Physics, 60*(7), 637-644.

Heller, P., Keith, R., & Anderson, S. (1992). Teaching problem solving through cooperative grouping. Part 1: Group versus individual problem solving. *American Journal of Physics, 60*(7), 627-636.

Hiebert, J., & Lefevre, P. (2013). Conceptual and procedural knowledge in Mathematics: An introductory analysis. In J. Hiebert (Ed.), *Conceptual and procedural knowledge: The case of mathematics (pp. 1-23).* New York: Routledge.

Hodgson, A. J., Ostafichuk, P., & Sibley, J. (2005). *Team-based learning in the design modules of a new, integrated, 2nd year curriculum at UBC.* Paper presented at the 2nd CDEN International Conference, Kananaskis, Alberta, Canada.

Houkes, W. (2009). The nature of technological knowledge. In A. Meijers (Ed.), *Handbook of the philosophy of science: Philosophy of technology and engineering sciences* (pp. 309-350) (Vol. 9). Amsterdam: North Holland.

James, M. (2006). Assessment, teaching and theories of learning. In J. Gardner (Ed.), *Assessment and learning* (1st ed., pp. 47-60). London: SAGE.

Johnson, B., & Christensen, L. B. (2008). *Educational research: Quantitative, qualitative, and mixed approaches* (3rd ed.). Los Angeles: Sage Publications.

Johnson, B., & Christensen, L. B. (2014). *Educational research: Quantitative, qualitative, and mixed approaches* (5th ed.). California: Sage.

Johnson, D. W., & Johnson, R. T. (2013). *Joining together: Group theory and group skills* (11th ed.). Harlow: Pearson.

Johnson, D. W., Johnson, R. T., & Johnson-Holubec, E. (2008). *Cooperation in the classroom* (8th ed.). Halifax: Interaction Book Company.

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational Researcher, 33*(7), 14-26.

Johnstone, A. H. (1993). Introduction. In C. Wood & R. Sleet (Eds.), *Creative problem solving in Chemistry*. London: The Royal Society of Chemistry.

Jonassen, D., Strobel, J., & Lee, C. B. (2006). Everyday problem solving in engineering: Lessons for engineering educators. *Journal of Engineering Education, 95*(2), 139-151.

Kagan, S., & Kagan, M. (2009). *Kagan cooperative learning*. San Clemente, California: Kagan Publishing.

Karimi, A., & Manteufel, R. D. (2012). *Assessment of student knowledge in an introductory thermodynamics course.* Paper presented at the ASEE Annual Conference and Exposition, San Antonio, Texas.

Kautz, C. H., & Schmitz, G. (2007). *Probing student understanding of basic concepts and principles in introductory engineering thermodynamics.* Paper presented at the ASME 2007 International Mechanical Engineering Congress and Exposition, Seattle, Washington, USA.

Keith, J., Silverstein, D., & Visco, D. (2008). Ideas to consider for new Chemical engineering educators: Part 2. *Chemical Engineering Education,* 44(4): 306-317.

Könings, K. D., Brand-Gruwel, S., & Van Merriënboer, J. J. G. (2005). Towards more powerful learning environments through combining the perspectives of designers, teachers, and students. *British Journal of Educational Psychology, 75*(4), 645-660. doi:10.1348/000709905X43616

Kooloos, J. G. M., Klaassen, T., Vereijken, M., Van Kuppeveld, S., Bolhuis, S., & Vorstenbosch, M. (2011). Collaborative group work: Effects of group size and assignment structure on learning gain, student satisfaction and perceived participation. *Medical Teacher, 33*(12), 983-988. doi:10.3109/0142159X.2011.588733

Krauss, S. E. (2005). Research paradigms and meaning making: A primer. *Qualitative Report, 10*(4), 758-770.

Kuhn, T. S. (1970). *The structure of scientific revolutions* (2nd ed.). Chicago: University of Chicago Press.

Kuo, E., Hull, M. M., Gupta, A., & Elby, A. (2013). How students blend conceptual and formal mathematical reasoning in solving physics problems. *Science Education, 97*(1), 32-57.

Kvale, S., & Brinkmann, S. (2009). *Interviews: Learning the craft of qualitative research interviewing* (2nd ed.). USA: SAGE.

Larochelle, M., Bednarz, N., & Garrison, J. W. (1998). *Constructivism and education.* Cambridge, New York: Cambridge University Press.

Layton, E. (1971). Mirror-image twins: The communities of science and technology in 19th-century America. *Technology and Culture, 12*(4), 562-580.

Ledlow, S., White-Taylor, J., & Evans, D. L. (2002). *Active/cooperative learning: A discipline-specific resource for engineering education.* Paper presented at the American Society for Engineering Education annual Conference & Exposition, Montreal, Canada.

Leonard, W. J., Gerace, W. J., Dufresne, R. J., & Mestre, J. P. (1999). *Minds on Physics: Conservational laws and concept-based problem solving. Teacher guide.* Dubuque, Iowa: Kendall Hunt.

Liu, Y., Mauthner, S., & Schwarz, L. (2009). Using CPS to promote active learning. In H. Song, & Kidd, T. (Eds.), *Handbook of research on human performance and instructional technology* (pp. 106-117). Hershey, NY: Information Science Reference.

Lochhead, J. (1985). Teaching analytic reasoning skills through pair problem solving. In J. W. Segal, S. F. Chipman, & R. Glaser (Eds.), *Thinking and learning skills (Volume 1): Relating instruction to research* (pp. 109-131). Hillsdale, NJ: Lawrence Erlbaum Associates.

Lourenço, O. (2012). Piaget and Vygotsky: Many resemblances, and a crucial difference. *New Ideas in Psychology, 30*(3), 281-295. doi:10.1016/j.newideapsych.2011.12.006

Maceiras, R., Cancela, A., Urrejola, S., & Sanchez, A. (2011). Experience of cooperative learning in engineering. *European Journal of Engineering Education, 36*(1), 13-19.

Mason, M. (2010). Sample size and saturation in PhD studies using qualitative interviews., *Forum: Qualitative Social Research*, *11*(3).

Matthews, M. R. (2002). Constructivism and science education: A further appraisal. *Journal of Science Education and Technology, 11*(2), 121-134.

McLeish, K. (2009). *Attitudes of students towards cooperative learning methods at Knox Community College: A descriptive study*. Retrieved from Jamaica: http://files.eric.ed.gov/fulltext/ED506779.pdf

Meijers, A. (Ed.) (2009). *Philosophy of technology and engineering sciences* (1st ed.). (Vol. 9). Amsterdam: North Holland.

Mentz, E., Van der Walt, J. L., & Goosen, L. (2008). The effect of incorporating cooperative learning principles in pair programming for student teachers. *Computer Science Education, 18*(4), 247-260.

Merriam-Webster dictionary. (2014). Encyclopedia Britannica.

Michaelsen, L. K., & Sweet, M. (2008). Creating effective team assignments. In L. K. Michaelsen, D. X. Parmelee, K. K. McHanon, & R. E. Levine (Eds.), *Team-based learning for health professions education: a guide to using small groups for improving learning.* Sterling, VA: Stylus.

Michaelsen, L. K., & Sweet, M. (2011). Team-based learning. *New Directions for Teaching and Learning* (128), 41-51. doi:10.1002/tl.467

Midkiff, K. C., Litzinger, T. A., & Evans, D. L. (2001). *Development of engineering thermodynamics concept inventory instruments.* Paper presented at the 31st Annual Frontiers in Education Conference, Reno, USA.

Miller, R. L., Streveler, R. A., Yang, D., & Roman, A. I. S. (2011). Identifying and repairing student misconceptions in thermal and transport science: Concept inventories and schema training studies. *Chemical Engineering Education, 45*(3), 203-206.

Mitcham, C., & Schatzberg, E. (2009). Defining technology and the engineering sciences. In A. Meijers (Ed.), *Philosophy of technology and engineering sciences* (Vol. 9). Amsterdam: North Holland.

Molefe, F. K. (2006). *Mathematical knowledge and skills needed in physics education for grades 11 and 12* (Master's dissertation). North West University, Potchefstroom.

Moran, M. J., & Shapiro, H. N. (1995). *Fundamentals of engineering thermodynamics* (3rd ed.). Hoboken, NJ: John Wiley & Sons.

Morgan, B. (2005). Cooperative learning: Teacher use and social integration. Retrieved from http://www.nationalforum.com/Electronic%20Journal%20Volumes/Morgan,%20Bobbette%20M.%20Cooperative%20Learning%20Teacher%20Use%20and%20Social%20Integration.pdf

Morgan, D. L. (2007). Paradigms lost and pragmatism regained methodological implications of combining qualitative and quantitative methods. *Journal of Mixed Methods Research, 1*(1), 48-76. doi:10.1177/2345678906292462

Morgan, P. (2000). Paradigms lost and paradigms regained? Recent developments and new directions for HRM/OB in the UK and USA. *International Journal of Human Resource Management, 11*(4), 853-866.

Mustoe, L. (2002). Mathematics in engineering education. *European Journal of Engineering Education, 27*(3), 237-240. doi:10.1080/0304790210141546

Nakhleh, M. B., & Mitchell, R. C. (1993). Concept learning versus problem solving: There is a difference. *Journal of Chemical Education, 70*(3), 190. doi:10.1021/ed070p190

Nebesniak, A. (2007). *Using cooperative learning to promote a problem-solving classroom*. Retrieved from https://www.google.co.za/url?sa=t&source=web&rct=j&url=http://digitalcommons.unl.edu/cgi/viewcontent.cgi%3Farticle%3D1022%26context%3Dmathmidsummative&ved=0ahUKEwj1rbTh16vVAhVjl8AKHd0IDH8QFggaMAA&usg=AFQjCNH8X9Vj-Pdg7zJal1juigdUvLfdww

Neo, M. (2004). Cooperative learning on the web: A group based, student centred learning experience in the Malaysian classroom. *Australasian Journal of Educational Technology, 20*(2), 171-190.

Nurrenbern, S. C., & Pickering, M. (1987). Concept learning versus problem solving: Is there a difference? *Journal of Chemical Education, 64*(6), 508. doi:10.1021/ed064p508

Oakley, B., Felder, R. M., Brent, R., & Elhajj, I. (2004). Turning student groups into effective teams. *Journal of Student Centered Learning, 2*(1), 9-34.

Okasha, S. (2002). *Philosophy of science: A very short introduction.* Oxford, UK: Oxford University Press.

Olson, B. W. (2005). *A practical application of team based learning to undergraduate engineering coursework.* Paper presented at the Midwest Section Conference of ASEE, Fayetteville, AR.

Ormrod, J. E. (2009). *Human learning* (5th ed.). Upper Saddle River, N.J.: Pearson Prentice Hall.

Ouweneel, W. J. (1992). *Natuurwetenskap en natuurbeskouing*. Potchefstroom: Potchefstroomse Universiteit vir CHO.

Oxford English Dictionary. (2014). Retrieved from http://www.oed.com/view/Entry/172672?redirectedFrom=science#eid.

Pool, J., & Reitsma, G. (2017). Adhering to scientific and ethical criteria for scholarship of teaching and learning. *Critical Studies in Teaching & Learning*, (5)1, 36-48.

Prince, M. J. (2004). Does active learning work? A review of the research. *Journal of Engineering Education, 93*(3), 223-229.

Prince, M. J., & Felder, R. M. (2006). Inductive teaching and learning methods: Definitions, comparisons, and research bases. *Journal of Engineering Education, 95*(2), 123-138.

Prince, M. J., & Felder, R. M. (2007). The many faces of inductive teaching and learning. *Journal of College Science Teaching, 36*(5), 5.

Prince, M. J., Vigeant, M. A., & Nottis, K. E. K. (2013). *Assessment and repair of critical misconceptions in engineering heat transfer and thermodynamics*. Paper presented at the ASEE Annual Conference, Atlanta, Georgia.

Probst, P. E., & Zhang, Y. (2013). *A gentle bridge between dynamics and thermodynamics*. Paper presented at the 120th ASEE Annual Conference and Exposition, Atlanta, Georgia.

Radder, H. (2009). Science, technology and the science-technology relationship. In A. Meijers (Ed.), *Handbook of the philosophy of science: Philosophy of technology and engineering sciences* (Vol. 9). Amsterdam: North Holland.

Radovan, M., & Makovec, D. (2015). Adult learners' learning environment perceptions and satisfaction in formal education-case study of four East-European countries. *International Education Studies, 8*(2), 101-112. doi:10.5539/ies.v8n2p101

Ridenour, J., Feldman, G., Teodorescu, R., Medsker, L., & Benmouna, N. (2013). *Is conceptual understanding compromised by a problem-solving emphasis in an introductory physics course?* Paper presented at the 2012 Physics Education Research Conference, Philadelphia, PA.

Salta, K., & Tzougraki, C. (2011). Conceptual versus algorithmic problem-solving: Focusing on problems dealing with conservation of matter in Chemistry. *Research in Science Education, 41*(4), 587-609. doi:10.1007/s11165-010-9181-6

Schnelker, D. L. (2006). The student-as-bricoleur: Making sense of research paradigms. *Teaching and Teacher Education, 22*(1), 42-57. doi:10.1016/j.tate.2005.07.001

Schunk, D. H. (2004). *Learning theories: An educational perspective* (4th ed.). Upper Saddle River, NJ: Pearson/Merrill/Prentice Hall.

Serway, R. A. & Jewett, J. W. (2004). *Physics for scientists and engineers, with modern physics* (6th ed.). Belmont, CA: Thomson-Brooks/Cole.

Shenton, A. K. (2004). Strategies for ensuring trustworthiness in qualitative research projects. *Education for Information, 22*, 63-75.

Siemens, G. (2006). *Connectivism: Learning theory or pastime of the self-amused?* Manitoba, Canada: Learning Technologies Centre.

Silberberg, M. S. (2009). *Chemistry: The molecular nature of matter and change* (5th ed.). Boston: McGraw-Hill.

Singh, C. (2008). *Coupling conceptual and quantitative problems to develop student expertise in introductory physics.* Paper presented at the Proceedings of the Physics Education Research Conference, Edmonton, CA.

Smith, K. A., Sheppard, S. D., Johnson, D. W., & Johnson, R. T. (2005). Pedagogies of engagement: Classroom-based practices. *Journal of Engineering Education, 94*(1), 87-101.

Streveler, R. A., Miller, R. L., Santiago-Roman, A. I., Nelson, M. A., Geist, M. R., & Olds, B. A. (2011). Rigorous methodology for concept inventory development: Using the 'Assesment Triangle' to develop and test the thermal and transport science concept inventory (TTCI). *International Journal of Engineering Education, 27*(5), 968-984.

Surif, J., Ibrahim, N. H., & Dalim, S. F. (2014). Problem solving: Algorithms and conceptual and open-ended problems in Chemistry. *Procedia - Social and Behavioral Sciences, 116*(0), 4955-4963. doi:http://dx.doi.org/10.1016/j.sbspro.2014.01.1055

Taylor, P. L. (1963). Mathematics as an educational discipline for the engineer. *Electrical Engineers, Proceedings of the Institution of, 110*(4), 775-784. doi:10.1049/piee.1963.0105

Ten Cate, O. (2001). What happens to the student? The neglected variable in educational outcome research. *Advances in Health Sciences Education, 6*(1), 81-88. doi:10.1023/A:1009874100973

Tongchai, A., Sharma, M. D., Johnston, I. D., Arayathanitkul, K., & Soankwan, C. (2009). Developing, evaluating and demonstrating the use of a conceptual survey in mechanical waves. *International Journal of Science Education, 31*(18), 2437-2457. doi:10.1080/09500690802389605

Turns, S. R., & Van Meter, P. N. (2011). *Applying knowledge from educational psychology and cognitive science to a first course in thermodynamics.* Paper presented at the ASEE Annual Conference and Exposition, Vancouver, Canada.

Van Niekerk, W. M. K., & Mentz, E. (2013). *The development of a cooperative teaching-learning strategy for engineering thermodynamics.* Paper presented at the second biennial Conference of the South African Society for Engineering Education, Cape Town, South Africa.

Van Niekerk, W. M. K., Mentz, E., & Smit, W. (2011). *Co-operative learning in thermodynamics: Solving problems in pairs.* Paper presented at the first biennial Conference of the South African Society for Engineering Education, Stellenbosch, South Africa.

Wallace, M. B. (2014). *Characteristics of problem solving success in physics* (Doctoral Thesis)., University of Edinburgh.

Wattanakasiwich, P., Taleab, P., Sharma, M. D., & Johnston, I. D. (2013). Development and implementation of a conceptual survey in thermodynamics. *International Journal of Innovation in Science and Mathematics Education, 21*(1), 29-53.

Whimbey, A., & Lochhead, J. (1979). *Problem solving and comprehension: A short course in analytical reasoning*. Philadelphia: Franklin Institute Press.

Whimbey, A., Lochhead, J., & Narode, R. (2013). *Problem solving and comprehension* (7th ed.). New York: Routledge.

Williams, L., & Kessler, R. (2003). *Pair programming illuminated.* Boston: Addison-Wesley.

Williams, L., Kessler, R. R., Cunningham, W., & Jeffries, R. (2000). Strengthening the case for pair programming. *IEEE Software*, July/August: 19-25.

Williams, L., & Upchurch, R. L. (2001). *In support of student pair-programming.* Paper presented at the 32nd Technical Symposium, Special Interest Group Computer Science Education (SIGCSE), Charlotte, North Carolina.

Wood, C. (2006). The development of creative problem solving in chemistry. *Chemistry Education Research and Practice, 7*(2), 96-113.

Woods, D. R. (2000). An evidence-based strategy for problem solving. *Journal of Engineering Education, 89*(4), 443-459.

Zdunkowski, W., & Bott, A. (2004). *Thermodynamics of the atmosphere: A course in theoretical meteorology.* New York: Cambridge University Press.

Zemke, S. C., Elger, D. E., & Beller, J. (2004). *Tailoring cooperative learning events for engineering classes.* Paper presented at the 2004 Annual Conference & Exposition of the American Society for Engineering Education, Salt Lake City, Utah.

Zhang, Y., Fang, Y., Wei, K. K., & Wang, Z. (2012). Promoting the intention of students to continue their participation in e-learning systems: The role of the communication environment. *Information Technology and People, 25*(4), 356-375. doi:10.1108/09593841211278776

Ziman, J. (1994). *An introduction to science studies*. New York: Cambridge University Press.

APPENDICES

Appendix A: Letter from the Ethics committee

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Ethics Committee
Tel +27 18 299 4852
Email Ethics@nwu.ac.za

1 July 2013

ETHICS APPROVAL OF PROJECT

The North-West University Ethics Committee (NWU-EC) hereby approves your project as indicated below. This implies that the NWU-EC grants its permission that, provided the special conditions specified below are met and pending any other authorisation that may be necessary, the project may be initiated, using the ethics number below.

Project title: Evaluering van Gesamentlike Probleem Oplossing (GPO) as 'n lewensvatbare alternatiewe onderrig/leer strategie in die onderrig van Termodinamika vir Meganiese Ingenieurs	
Project Leader: Prof E Mentz	
Ethics number:	N W U - 0 0 0 2 7 - 1 3 - A 2 Status: S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation
Approval date: 2013/05/09	**Expiry date:** 2018/05/08

Special conditions of the approval (if any): None

General conditions:

While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, please note the following:

- *The project leader (principle investigator) must report in the prescribed format to the NWU-EC:*
  - *annually (or as otherwise requested) on the progress of the project,*
  - *without any delay in case of any adverse event (or any matter that interrupts sound ethical principles) during the course of the project.*
- *The approval applies strictly to the protocol as stipulated in the application form. Would any changes to the protocol be deemed necessary during the course of the project, the project leader must apply for approval of these changes at the NWU-EC. Would there be deviated from the project protocol without the necessary approval of such changes, the ethics approval is immediately and automatically forfeited.*
- *The date of approval indicates the first date that the project may be started. Would the project have to continue after the expiry date, a new application must be made to the NWU-EC and new approval received before or on the expiry date.*
- *In the interest of ethical responsibility the NWU-EC retains the right to:*
  - *request access to any information or data at any time during the course or after completion of the project;*
  - *withdraw or postpone approval if:*
    - *any unethical principles or practices of the project are revealed or suspected,*
    - *it becomes apparent that any relevant information was withheld from the NWU-EC or that information has been false or misrepresented,*
    - *the required annual report and reporting of adverse events was not done timely and accurately,*
    - *new institutional rules, national legislation or international conventions deem it necessary.*

The Ethics Committee would like to remain at your service as scientist and researcher, and wishes you well with your project. Please do not hesitate to contact the Ethics Committee for any further enquiries or requests for assistance.

Yours sincerely

Prof Amanda Lourens
(chair NWU Ethics Committee)

Appendix B: Invitation and questions: Student interviews

Appendix B1: Invitation

Each student was sent a personal invitation by email:

<u>Subject:</u> Interview: Thermodynamics

Dear Student A,

As part of our research into teaching strategies I would like to hear from you how you experienced the approach we followed during the tutorials - where you cooperated in groups of two. You are one of fourteen students selected randomly. I am going to ask you a number of open ended questions that I prepared. There are therefore no right or wrong answers. I would appreciate it if we can schedule the interview for Tuesday 7, Wednesday 8, Thursday 9 or Friday 10 May. Please let me know if you accept the invitation? Also let me know what time will suit you. It will take approximately 20 minutes – in my office C317.3. Your participation is completely voluntary en you will not be discriminated against because of anything you say during the interview or if you decide not to participate.

Hope to hear from you soon!

Willem van Niekerk

Lecturer: Tutorials

Appendix B2: Interview introduction

Welcome! Thank you for making time for this interview. I would like to know how you experienced Pair Problems Solving as we implemented it in the tutorial sessions and need your honest opinion. Please be assured that you won't be disadvantaged by the answers you give. The questions I will be asking was formulated on purpose to be 'open-ended' and therefore does not have a right of wrong answer because we are interested in how you experienced the module. By participating, you give permission that I may use what is being said here, for research purposes. Do you mind if I record the interview?

Appendix C: Student assistant questionnaire

A personal invitation was sent to each student assistant by email:

Subject: Questionnaire with regards to thermodynamic tutorials.

Dear Student Assistant A,

The procedure we followed during the tutorials – Cooperative pair problem solving – where the students worked in pairs, is part of a research project focusing on teaching strategies. We would like to establish your experience of CPPS and in order to do this, a questionnaire is attached to this email. Please answer the questions in the Word document and send it to Willem van Niekerk at the address above. Your participation is entirely voluntary and anonymous. There will be no discrimination against anyone who decides not to participate. If you do complete the questionnaire, you also give the researcher permission to use the data for his research purposes.

Thank you!

Willem van Niekerk.

<u>CPPS Assistant questionnaire.</u>

1. What do you think of the way in which the tutorial was structured?

Type here

2. What did you observe with regards to cooperation between students?

Type here

3. To what extent do you think PPS gave a student the chance to dodge his or her personal responsibility of contributing towards solving the problems?

Type here

4. What did you observe with regards to the students' interpersonal and social skills in the groups they were working in?

Type here

5. How do you think the students feel about PPS? Please elaborate.

Type here

6. What is your opinion of PPS? Please elaborate.

Type here

Appendix D: Researcher’s memoirs

I kept a journal during the implementation of CPPS at both universities in 2013. The implementation of CPPS at University A took place during the first semester of 2013 and at University B during the second semester of 2013. I now implement CPPS every year when I present Thermodynamics. This memoir therefore includes my experiences at University B during the second semester of 2014, 2015 and 2016. (CPPS will again be implemented in 2017, but is not part of this study.) My experiences and perceptions are given below. It is done in the first person.

University A

Background

I was not in the employ employed by of University A, but they were kind enough to allow me to implement CPPS at their university, for which I am very grateful. I was responsible for preparing the tutorials as well as presenting the tutorial to the Afrikaans-speaking students. The resident lecturers and instructors were responsible for presenting the tutorial to the English-speaking students and presenting the lecturers to the Afrikaans-speaking group and the English-speaking group. At this university, it was also the custom that there were student assistants available to help during tutorials and grade the tutorial problems handed in by the students. Usually there were three to four assistants for each language group.

Because I was a guest and only a team member, I had to take special care to take local established procedures and practices into consideration, keep everybody informed and get everybody’s cooperation. I was not involved with setting the mid-term and final examinations and therefore was not aware, and to be honest, not so concerned with the academic performance of the students. As long as nobody complained about this lecturer from another university (me), implementing this unfamiliar procedure, I was happy. Also, it was also not possible for me to compare the CPPS tutorials with tutorials in Thermodynamics of previous years at this university as I was not involved in previous (and subsequent) years.

Perceptions

I remember vividly, during one of the first CPPS tutorials, shortly after the students received their problem set that I wanted to tell them to quiet down and start working. Then I realized that they **were** working, that the noise of conversation is exactly what was supposed to happen. It was clear that they were solving the problems together. I realized that they were explaining to each other, searching for solutions together.

I was used to be the one who did the talking, who did the explaining, expecting the students to be quiet and pay attention to what I was saying, or solve problems on their own, in silence. It was a huge relief to realize that it was not the case anymore, that it was not necessary for me to explain often trivial detail to individual students, that all the explaining that was taking place did not have to come from me. Furthermore, that much more learning was most probably taking place than would have been the case if I was the only one teaching.

Also, when two students called me, it was easier to explain to two of them. Often one student was quicker to understand and I could leave it to him to explain to his or her partner so that I could attend to another pair. When it became clear that several students did not understand a concept, I explained to the whole class, on the board. Again, that was followed by a feeling of relief because I knew that one student could explain to the other if he or she did not understand every aspect of my explanation.

There were other impressions as well, as discussed next.

Cooperation between students

Upon receiving the problem set, students almost involuntary turned towards each other, read, and discussed the problem. It was obvious that they worked together, one doing the calculations, the other looking up values in the tables. The initial seat allocation for writing the individual test, was such that there was a seat open between students, but generally students moved to sit next to each other when they received the problems, to be able to read from the single problem sheet handed to each pair. In isolated cases, the seat between them remained open. I had the impression that students were more likely to remain in their seats when one of the students was a female student. One also got the impression that students of minority groups were more at ease when they worked together with one from their own group. One of the student assistant made the same observation. (TBC) When I noticed two students not cooperating I would address them but I and the student assistants were usually too busy to answer questions to make sure all groups cooperated.

Random seat allocation

University A

Despite motivating the random allocation of seats, there were always students ignoring the arrangement, sitting with friends. This had a snowball effect. For every student not sitting at his allocated seat, two students were affected: the student who was supposed to sit at the seat now occupied by the ‘cheater’ and the student now sitting alone because the student who was supposed to sit with him, was sitting with a friend.

Students received a piece of paper with a seat number upon entering the class and there was no record where students were supposed to sit and enforce the seat allocation. It was therefore left to the facilitator to try and ensure that students sat in their allocated seats. Some students made their dissatisfaction and irritation with not being able to sit with friends obvious, and it did take hard-nosed determination from the facilitator to enforce the arrangement and address students who obviously did not sit in their allocated seats. Despite our best efforts, there were always students who did not sit at their allocated seats.

Logistical challenges

At University A, two student assistants handed out the pieces of paper with seat numbers as students entered the class. The whole class therefore had to queue in front of the class. This invariably led to some congestion, but it was usually possible to fill the class in less than ten minutes. The class was scheduled to start at 14:00. Ten to fifteen minutes before 14:00 I asked students who spent their lunch hour in class, to leave the class and we tried to start filling the class several minutes before 14:00. Early in the semester there were several students coming late, but as they realized that the test started on time, the number of late-comers dwindled. We also had to guard a back door to prevent students bypassing the seat allocation.

Because two students handed in one answer set, the grading load on the student assistants was reduced by 50%. However, getting the graded copies back to the students posed a problem as there were two students and only one copy. Which of the two students should collect the graded copy? How should the graded copies be arranged? Alphabetically according the first author? How can the other student get a copy of their solution set? It often took two weeks for the problems to be graded and made available. By this time students often lost interest. In line with the instructions of the course coordinator, the final answer and the main points of the solution strategy were made available on the student website immediately after the tutorial. Several students complained that this was not sufficient.

Preparedness of students

The marks for the individual test were much lower than expected. The expectation was that most students will pass the tests. During the interviews, several students said that they found the individual test difficult. My intent was that any student who could follow the lectures and briefly reviewed the work before the test, should find the tests reasonable and pass easily. The fact that the students found the test difficult is perhaps an indication of how ineffective lectures are – and therefore how important the tutorials are as an opportunity for students to get to understand the work.

CPPS related work

The physical preparation work due to CPPS entailed printing and cutting the seat numbers. Setting a new set of tutorial problems for each tutorial was a lot of work but setting up new problems for each tutorial was normal practice at this university anyway. Also, at this university students did write an individual test at the end of the tutorial, so the setting of an individual test was not extra.

Running the tutorial required some extra effort. Before the tutorial seat numbers were placed on the benches next to the aisles to enable students to find their seats. The pieces of paper with the individual seat numbers had to be handed out at the door and it was necessary to keep an eye open for students who ignored their seat number and confront those suspected of cheating. This required some effort and determination. Furthermore, it was not possible to force two students to cooperate. When noticing a pair that did not cooperate they had to be addressed in a positive manner.

Appendix E: Letter from Statistical consultation services

SKD
SCS

NORTH-WEST UNIVERSITY
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Private Bag X6001, Potchefstroom
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Tel: 018 299-1111/2222
Web: http://www.nwu.ac.za

Statistical Consultation Services
Tel: +27 18 285 2447
Fax: +27 0 87 231 5294
Email: monique.vandeventer@nwu.ac.za

4 August 2017

Re: Thesis, Mr W van Niekerk, student number: 10191984

We hereby confirm that the Statistical Consultation Services of the North-West University analysed the data involved in the study of the above-mentioned student and assisted with the interpretation of the results. However, any opinion, findings or recommendations contained in this document are those of the author, and the Statistical Consultation Services of the NWU (Potchefstroom Campus) do not accept responsibility for the statistical correctness of the data reported.

Kind regards

SM Ellis

Prof SM Ellis (Pr. Sci. Nat)
Associate Professor: Statistical Consultation Services

Appendix F: Student questionnaire before exposure to CPPS

QUESTIONNAIRE: THERMODYNAMICS

Student number	

Dear student,

This is a survey aimed at establishing your experience of group work. This survey forms part of a research project focused on teaching strategies. Your participation is entirely voluntary and anonymous. The student number required above will only be used for purposes of comparing answers obtained before and after the course. There will be no discrimination against anyone who decides not to participate. If you do complete the questionnaire, you also give the researcher permission to use the data for research purposes.

SECTION A: Give your honest opinion of the statements below by crossing the appropriate number in each instance, to indicate the extent to which you agree with each statement:

	STATEMENT	**Do not agree at all.**	**Agree to a small extent.**	**Agree to a large degree.**	**Fully agree.**
1	When doing group work, everybody contributes equally towards attaining the group's goal.	1	2	3	4
2	I learn more working in a group compared to working on my own.	1	2	3	4
3	Conflict regularly occurs when doing group work.	1	2	3	4
4	During group work I can use my unique abilities to the advantage of the group.	1	2	3	4
5	When we do group work, the members of the group listen to everybody's contributions.	1	2	3	4
6	Group assignments taught me to cooperate better with other people.	1	2	3	4
7	It is a waste of my time if I have to help another member of the group.	1	2	3	4
8	All members of a group benefit equally by participating in group work.	1	2	3	4
9	During group work, all members are up to date with the work that is done by the group.	1	2	3	4

10	Everybody's contributions are necessary for the group to be successful.	1	2	3	4
11	When we do group work, I feel a sense of responsibility towards the group.	1	2	3	4
12	Group assignments are simply a collection of individual efforts.	1	2	3	4
13	When we do group work, group members help each other.	1	2	3	4
14	When we do group assignments, I have enough confidence to ask questions.	1	2	3	4
15	Group work is detrimental of good students.	1	2	3	4
16	Group work helped me to fit in socially.	1	2	3	4
17	Group work increases my stress levels.	1	2	3	4

SECTION B: OPEN QUESTIONS

1. If so, provide example(s) of something that you have learned because you were working in a group that you would not have learned if you were working alone.

____

____

____

____

____

2. If so, give an example of a problem experienced by a group to which you belonged, and explain how the problem was solved.

____

____

____

____

____

Appendix G: Student questionnaire after exposure to CPPS

THERMODYNAMICS QUESTIONNAIRE

Student number	

Dear student,

This is a survey aimed at establishing your experience of pair problem solving (PPS), the procedure we followed during the tutorials. This survey forms part of a research project focused on teaching strategies. Your participation is entirely voluntary. The student number required above will only be used for purposes of comparing answers obtained before and after the course. There will be no discrimination against anyone who decides not to participate. By completing the questionnaire, you give the researcher permission to use the data for research purposes.

Please note: Group / team refers to the two of you working together during a specific tutorial.

SECTION A: Give your honest opinion of the statements below by crossing the appropriate number in each instance, to indicate the extent to which you agree with each statement:

	STATEMENT	**Do not agree at all.**	**Agree to a small extent.**	**Agree to a large extent.**	**Fully agree.**
1	During CPPS both team members contributed equally towards attaining the group's goal.	1	2	3	4
2	I learned more by working with someone compared to working on my own.	1	2	3	4
3	Conflict regularly occurred during CPPS.	1	2	3	4
4	During CPPS I could use my unique abilities to the advantage of the group.	1	2	3	4
5	During CPPS my team mate listened to my contributions.	1	2	3	4
6	CPPS taught me to cooperate better with other people.	1	2	3	4
7	During CPPS it was a waste of time to help my team mate.	1	2	3	4
8	Both the team members benefitted equally from working together.	1	2	3	4
9	During CPPS both team members were up to date with the problem we were working on.	1	2	3	4

10	During CPPS my contribution was necessary for the group to be successful.	1	2	3	4
11	During CPPS I felt a sense of responsibility towards my group.	1	2	3	4
12	CPPS is simply a collection of two individual efforts.	1	2	3	4
13	During CPPS the two of us helped each other.	1	2	3	4
14	During CPPS I had enough confidence to ask my team mate questions.	1	2	3	4
15	CPPS is detrimental to the better student.	1	2	3	4
16	CPPS helped me to fit in socially.	1	2	3	4
17	CPPS increased my stress levels.	1	2	3	4
18	In a next subject, I would like to work in groups of two again.	1	2	3	4

SECTION B: OPEN-ENDED QUESTIONS

7. If relevant, please provide example(s) of something that you have learned because of CPPS that you would not have learned if you were working alone.

____
____
____
____

8. If relevant, give an example of a problem experienced by a CPPS group to which you belonged, and explain how the problem was solved (if at all).

____
____
____
____

Appendix H: Concept inventory

Thermodynamics Concept Inventory

Dear student,

This is a survey of your understanding of some Thermodynamics concepts. Your participation is completely voluntary and anonymous. You will not be discriminated against in any way if you decide not to participate. The results are used solely for research purposes in an effort to improve teaching methods. You completion of this questionnaire will be seen as your approval for using the results for research purposes. Thank you for your participation.

Symbol obtained in your matric exam for Mathematics……………………………………………..
Physical Sciences………………………………………….
Examination board State school; IEB; Other……………..

In what year did you pass Thermodynamics INGM222?...

Please indicate your answer by circling the (a), (b), or as appropriate.

1. Gaseous hydrogen (H_2) and oxygen (O_2) are mixed in a 2:1 molar proportion (2 moles of H_2 per mole of O_2) in a rigid, constant volume tank at temperature T_1 and pressure P_1. A spark in the tank causes all of the H_2 and O_2 to react to form gaseous water according to the following reaction:

$$2H_2 + O_2 = 2H_2O$$

   After the reaction, only water vapor is present in the tank. The tank contents are brought back to the original temperature T_1 without condensation taking place while the tank volume stays constant. You may assume that H_2, O_2, and gaseous H_2O all behave as ideal gases. P_2 is the pressure of the water vapor. [1] What do you think about the final pressure (P_2?)

   a) $P_2>P_1$
   b) $P_2=P_1$
   c) $P_2<P_1$
   d) Insufficient information

2. I base my answer in Question 1 on the fact(s) that: (Choose one statement from the list below. All statements are true. Choose the one you based your answer on. [1]

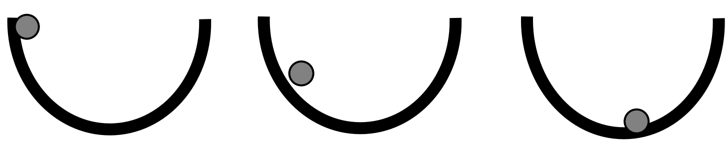
   e) The total mass inside the container stayed constant. The mass of the water vapor is equal to the mass of hydrogen plus the mass of oxygen
   f) The total number of moles decreased. The number of moles of water vapor is less than the number of moles of oxygen and hydrogen.
   g) Energy is released by the reaction between Hydrogen and Oxygen
   h) The temperature returned to the original value: T2=T1

3. Superheated steam, in a rigid container, is heated from T_1 to T_2. Consider possible relationships between pressure and temperature when steam is heated at constant volume:

   i) In engineering calculations, a linear relationship – as in the ideal gas law – can be assumed.
   j) The relationship is not linear.
   k) The value of pressure at a specific temperature and specific volume can only be obtained from the steam tables.
   l) Depending on the value of the temperature and the pressure, the relationship can be taken to be linear or non-linear.

4. Consider a marble that is held at the lip of a bowl. The marble is released, with no force added, and begins to roll down into the bowl. Assuming the rolling process is frictionless, for which of the figures below does the ball have maximum total energy?

A **b** **c** **D** **e**



D: Energy is the same for all positions

e: Insufficient information

5. A container is filled with equal amounts of liquid water and ice cubes. The container has an opening to the atmosphere with the result that the pressure of the contents of the container is also at atmospheric pressure (101.3kPa) and remains so during the process. The contents are well mixed so that the temperature everywhere in the container is the same at any specific instant. The melting temperature of ice at 101.325kP is 0°C.

Heat is slowly added to the container with the result that the ice starts to melt. The heating is continued until the liquid water starts to boil (at 100°C) and steam starts to form. The steam escapes through the opening with the result that the pressure inside remains constant. The heating continues until the temperature of the steam inside the container rises to 150°C. Indicate on the graph below how the temperature changed from the initial value (at time t=0) to the final value (150°C) at time t=T. Use a ruler where necessary.

6. A pot of water, open to the atmosphere, contains boiling water. Now the pot is sealed by a tight lid, and continued heating causes the pressure to rise. Compared to before the lid was added, the temperature:

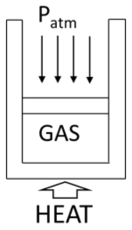
(a) Increases

(b) Remains the same

(c) Decreases

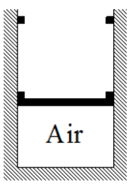
(d) Insufficient information.

7. Consider a gas heated reversibly and <u>expanding</u> in a sealed, frictionless, piston-cylinder arrangement, where the piston mass and the atmospheric pressure above the piston remain constant. During the process the temperature of the gas increases significantly. Complete the table below:



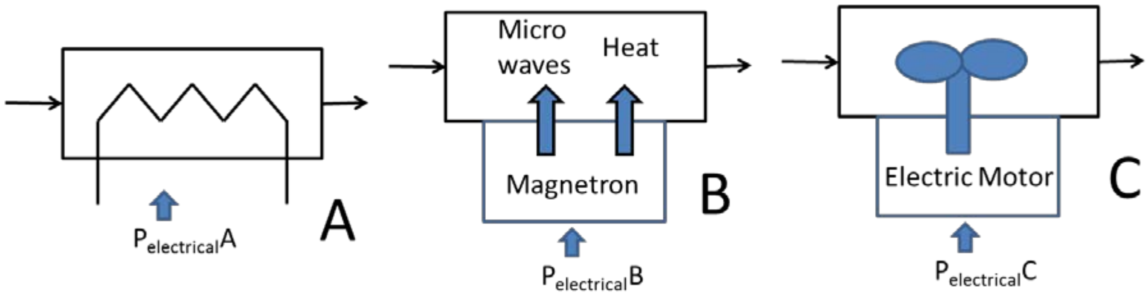
		Increases (>0)	Stays constant (=0)	Decreases (<0)	Cannot say
a) .	Pressure (P_2-P_1)				
b) .	Internal energy (u_2-u_1)				
c) .	Entropy (s_2-s_1)				

8. Air at high pressure and ambient temperature is contained in a perfectly insulated piston-cylinder device as shown on the right (State 1). Stops prevent the piston from moving up. The stops are now removed and the piston quickly rises, pushing away the atmospheric air above it until a second set of stops is encountered that prevents it from leaving the cylinder (State 2). Fill in the table below:



		Increases (>0)	Stay constant (=0)	Decreases (<0)	Cannot say
a) .	Internal energy (u_2-u_1)				
b) .	Temperature (T_2-T_1)				
c) .	Entropy (s_2-s_1)				

9. Consider three methods to heat water. All processes uses a perfectly-insulated tank filled with water. Water enters the tank at 10°C and exits at 50°C at a sufficient pressure to prevent boiling. The tank in Process A is fitted with an electric resistance heating element. In process B, the same perfectly-insulated tank is used but the water is heated by microwaves. In the magnetron, most of the electrical energy is converted into microwaves which is absorbed by the water but because of the electrical resistance of the magnetron, a little bit of heat is generated in the magnetron. In this process this heat is also transferred to the water. (In a domestic microwave oven this heat is removed by a fan and lost to the environment.) In the third process, the electrical energy is fed to a 100% efficient electric motor (all electric energy converted into mechanical energy). The shaft of the motor enters the water tank. A propeller is fitted to the end of the shaft stirring the water violently, causing turbulence and friction between the walls of the container and the water and also between the propeller and the water. The kinetic energy of the water leaving and entering all three tanks can be ignored. P is electrical power in kW.



The efficiency of the water heating process (η=Q/P) is defined as the rate of increase of the energy of the water (Q=Energy in – Energy out) in kW divided by the amount of electrical energy ($P_{electrical}$) in kW, provided to each system. Fill in the table below for the efficiency of each water heating process:

Efficiency (η)	A (Electrical)	B (Microwave heating)	C (Electric motor and propeller)
Measurably greater than 1			
Equal to one or essentially equal to one.			
Significantly lower than 1			
Cannot say			

10. Consider the two reversible heat engines (RHE) below. The heat engines and all associated processes (e.g. the heat transfer) are reversible. Heat is supplied to the two engines at a rate of 100kW. The only difference is that heat source A supplies heat at 900K and heat source B supplies heat at 1000K. Both heat engines reject heat to a low temperature heat sink at 298K. Mechanical work (W) is performed by the heat engines.

Which one of the following statement(s) is/are true:

(Note that more than one can be true)

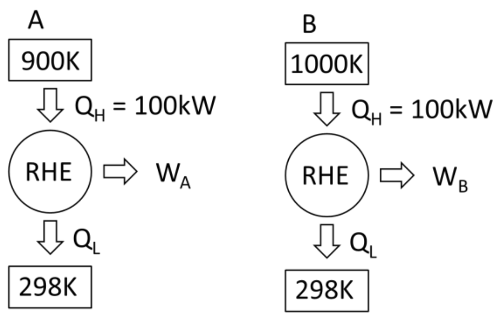
a) System A will perform the most work.

b) W_A=W_B but both smaller than 100kW

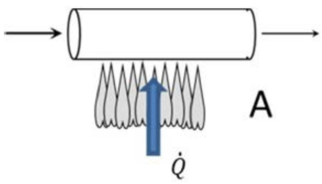
c) System B will perform the most work.

d) $W_A \neq W_B$ but both close to 100kW

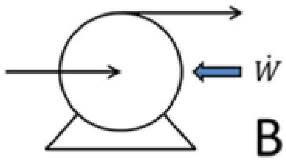
e) Not enough information



11. Consider two ideal systems. In system A, water at T_{in} and P_{in} flows through a pipe. There is no friction between the pipe wall and the water and no turbulence. The water is heated reversibly by the addition of thermal energy at a rate of $\dot{Q}$ [kW]. The pressure drop is zero ($P_{out} = P_{in}$) while the temperature increases substantially ($T_{out}>T_{in}$). In system B, water at the same inlet conditions (T_{in} and P_{in}) flows to a reversible adiabatic (no heat transfer with the environment) pump where shaft wor at a rate of $\dot{W}$ [kW] is required and the pressure rises substantially ($P_{out}>P_{in}$) whil the temperature stays essentially constant ($T_{out} \approx T_{in}$). Complete the tables below:



	Enthalpy (h_{out}-h_{in})	
	A	B
Increases substantially (>0)		
Stays constant (0)		
Decreases substantially(<0)		
Insufficient information		
Don't know		



	Internal energy (u_{out}-u_{in})	
	A	B
Increases substantially (>0)		
Stays constant (0)		
Decreases substantially (<0)		
Insufficient information		
Don't know		

	Entropy (s_{out}-s_{in})	
	A	B
Increases substantially (>0)		
Stays constant (0)		
Decreases substantially (<0)		
Insufficient information		
Don't know		

12. Consider the two heat engines operating between a high temperature heat source and a low temperature heat sink. One is a reversible (ideal) heat engine where all the associated processes (like heat transfer) are also reversible and one is an irreversible (real) heat engine where the associated processes may also be irreversible. Both receive high temperature heat at a rate of 100kW from the heat source and both reject heat at T_L to the heat sink.

Which of the following statement(s) is/are true?

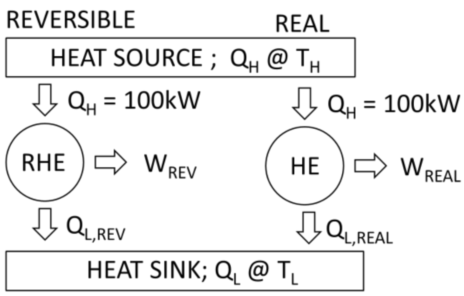
(Note more than one can be true.)

a) $W_{REV} > W_{REAL}$

b) W_{REV} can be as high as100kW

c) $W_{REV} = W_{REAL}$

d) Insufficient information



13. I base my answer in the previous question on the fact that:

(You may choose more than one)

a) Q_H in both instances is 100kW

b) The magnitude of W is determined by the temperature difference between the heat source and heat sink.

c) I need to know the type of heat engine – e.g. a reversible Carnot cycle will deliver more power than other types of reversible heat engines.

d) In reversible heat engines there are no losses

[1] The concepts for Question 1, 2, 10 and 13 are from the Thermal and Transport Concept Inventory Test (TTCI) developed by Ronald L Miller from the Colorado School of Mines and coworkers

[2] Questions 4, 6, 7 and 8 are from a concept inventory test by Midkiff et al. (2001) and are used with his permission.

Appendix I: Published article

Some of the results gathered during this study appear in the following article:

Van Niekerk W., & Mentz E. Cooperative Pair Problem Solving: A Strategy for Problem Solving Tutorials in the Engineering Sciences*. International Journal of Engineering Education* Vol. 31, No. 6(A), pp. 1516-1525, 2015.

Appendix J: Letter from language editor

DECLARATION BY LANGUAGE EDITOR

I hereby declare that I have language-edited the thesis by Mr WMK van Niekerk (student number 10191984 / 0000-0001-9947-6612), submitted in the fulfilment of the requirements for the degree Doctor Philosophiae in Curriculum development, innovation and evaluation at the Potchefstroom Campus of the North-West University, to the approval of Mr Van Niekerk and his supervisor:

Cooperative Pair Problem Solving: A Teaching-Learning Strategy for Tutorials in Mechanical Engineering Thermodynamics

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