# Cooperative Pair Problem Solving: A Strategy for Problem Solving Tutorials in the Engineering Sciences* 

WILLEM VAN NIEKERK<br>School of Mechanical and Nuclear Engineering, North-West University, South Africa. E-mail: willem.vanniekerk@nwu.ac.za<br>ELSA MENTZ<br>School for Natural Sciences and Technology for Education, North-West University, South Africa. E-mail:elsa.mentz@nwu.ac.za


#### Abstract

Engineering science courses, such as Thermodynamics, are often seen as difficult, and students have difficulty understanding the concepts and solving the problems. In an effort to improve the situation, we developed a well-structured, cooperative teaching-learning strategy, Cooperative Pair Problem Solving (CPPS), suitable for large groups (more than one hundred students) for implementation during tutorial sessions. CPPS will be of interest to educators already making use of tutorial sessions where students solve problems under the guidance of the lecturer and/or assistants. For educators expecting students to solve problems on their own, as homework, CPPS presents a viable alternative strategy to harness the proven advantages of Cooperative Learning. This article describes the procedure we followed with the implementation of CPPS during the tutorials. It further reports on the extent to which we were able to structure the five elements of CL and the effect this had on the tutorials. The study was performed at two universities in South Africa. The population comprised the second-year engineering students taking their first course in Thermodynamics - in total, approximately 400 students in three groups. The students and assistants completed questionnaires and two observers were asked to attend tutorials and report on their observations. There was almost universal agreement that CPPS led to effective cooperation between the students. From the questionnaires, it was clear that positive interdependence was sufficiently structured into the procedure. The majority of students engaged in promotive interaction and took responsibility to complete the task. The students possessed sufficient social skills to work effectively together, and group processing was effected by letting the groups grade their own work. It was found that an effective group formation procedure is vital for the successful implementation of CPPS otherwise students tend to sit with friends, and positive interdependence and promotive interaction suffer. Although CPPS was developed in a Thermodynamics environment, we are convinced that it can also be implemented successfully in other engineering science and even pure science courses where instructors want to implement CL during problem solving tutorials.


Keywords: cooperative learning; large groups; pair problem solving; Thermodynamics

## 1. Introduction

Thermodynamics is integral to any undergraduate mechanical engineering programme, and is often perceived as difficult to master and pass [1, 2]. In assessments, students normally have to prove that they have mastered the content by solving a number of problems. A good deal of emphasis is therefore placed on problem solving. Textbooks explain to students how to solve problems in a systematic and orderly manner. In the text, worked-out examples are presented, and at the end of each chapter, a large number of problems are also provided [3, 4]. To develop their own problem solving skills during the semester, students are usually required to solve a number of problems, either on their own or during tutorials under the guidance of a lecturer and/or teaching assistant(s) [1, 5].

The tutorials are only one part of the teaching strategy. Students are normally also expected to attend lectures where the theoretical contents are covered and concepts explained. It seems a lecturer-
centred teaching strategy is common [6, 7]. The student is passive-a 'sponge soaking up knowledge' or a 'jar to be filled' [8, 9] while the lecturer is responsible for presenting the material clearly so that the student can understand it easily.

Much to the frustration of lecturers, students often remain passive during problem solving and instead of developing their own problem solving strategies, demand that the lecturer do more problems in class [10] or increasingly get hold of the solution manual containing the solutions to end-ofchapter problems [11] as well as, in our experience, obtain copies of solved tutorial, test and examination problems from a variety of sources.

Active learning has been promoted as a strategy to make students less passive by engaging them in the learning process. The Centre for Teaching and Learning at the University of Minnesota [12] lists four active learning activities: talking and explaining, listening, writing, as well as reading and reflecting. The Centre describes several activities where students work in pairs. Richard Felder, a chemical
engineer, has done much work to promote active learning [13, 14] and considers that Think-PairShare and Think-Aloud-Pair-Problem-Solving are particularly effective.

We tried to implement pairing strategies during lectures when students had to solve problems, and found that this was not straightforward to implement at all-especially in large classes of one hundred students or more. The formation of pairs was not easy. It was not obvious who should work together, and students were often reluctant to collaborate with strangers or break up groups of three in order to form a pair with a single student. Felder suggests strategies to overcome these problems [15] but we eventually abandoned our efforts as we felt this technique was not effective-pair formation was problematic and it took dogged determination to overcome student resistance. Even then, having formed pairs, it seemed from casual observation that cooperation in many cases was not effective.

As tutorials focus on a single activity-problem solving-implementing some form of active learning should be easier to manage; therefore, we decided to implement active learning during the tutorials. However, we could not find a suitable, well-structured strategy that was suitable for large classes.

Williams and Kessler [16] developed Pair Programming (PP) as a formal, collaborative strategy for the effective solving of computer programming problems. PP was implemented with success in the teaching of computer programming by Williams and Upchurch [17]. Mentz, Van der Walt and Goosen [18] conducted an extensive review of the advantages and disadvantages of PP and found that its effectiveness could be improved by the incorporation of the elements associated with CL as described by Johnson and Johnson [19]. Encouraged by the success of PP and the improvement that could be brought about as a result of the incorporation of the elements of CL [18] and because of the similarities between Computer Programming and Thermodynamics (both subjects rely on logic, in both a systematic approach is necessary, and in both the solution to problems may not be immediately apparent), we decided to develop a formal cooperative teaching-learning strategy, CPPS, for Thermodynamics where students had to work in pairs during tutorials.

The purpose of this article is to describe the strategy we followed with the implementation of CPPS during the tutorials, as well as to evaluate the extent to which we were able to structure the five elements of CL into the strategy and the effect this had on the tutorials as perceived by the students, teaching assistants and lecturers.

## 2. Cooperative learning

Cooperative Learning (CL) is an instructional technique where students work together in small groups to achieve common goals [19, 20]. Because the students are engaged in their own learning, CL can be regarded as a form of active learning [20].

Johnson, Johnson and Johnson-Holubec [19] describe three theoretical perspectives that have guided research on and the practice of CL-the social interdependence, cognitive developmental and behavioural learning theories. The social interdependence theory states that in a group where positive interdependence exists, students will encourage and facilitate each other's efforts to learn [19].

According to the cognitive development perspective, learning takes place through coaching, modelling and the provision of conceptual frameworks for understanding (scaffolding) [19]. This scaffolding can be provided by more knowledgeable persons but the role that peers can play has also been recognised [21]. Considering problem solving as a skill [14, 22] illustrates a possible scaffolding mechanism. According to Whimbey, Lochead and Narode [23], in order to master a skill like problem solving, the skill must first be demonstrated by a skilled problem solver, verbalising his or her thoughts. This makes the process, which is normally not visible, clear to the student. Then the students should practice problem solving and receive feedback from the skilled person. During Thinking-Aloud-Pair-Problem-Solving, which Whimbey and Lochead [23] originally developed, another student asks questions and provides feedback. This makes the students' thinking visible to themselves and others and gives them the opportunity to go through the metacognitive process of taking an objective view of their own and their partners' understanding. This helps them to develop their problem solving skills. Even when the abilities of the students differ, a strong student will gain a deeper understanding, which comes with teaching something to someone else [14].

In behavioural learning, it is assumed that rewarding the group for their group effort, will encourage individuals to work hard in order to help the group succeed [19].
Working with peers also promotes learning due to social considerations. Williams and Kessler [16] discuss several synergistic behaviours of persons working in pairs. Firstly, it puts a positive form of pressure on each member of the pair to focus on the task and make a contribution. Familiarity between team members may reduce this pressure, and therefore it is best if students are not allowed to choose their own partners [19, 24]. Students will be more willing to admit their ignorance or venture a sugges-
tion to a fellow student than to the lecturer or to the whole class [16]. A student working alone is more likely to quit when encountering problems [19]. Another advantage is synergy. Each member of the pair can contribute his or her understanding and complement the other partner, and in the process increase their chances of solving the problem [16].

The advantages of CL, over individualistic and competitive learning, have been proved in numerous studies [19]. Three types of CL are distinguished. During informal CL, students work on simple tasks in ad hoc groups for short periods lasting from a few minutes to one class period. Formal CL groups are more structured, perform tasks that are more complex and stay together for longer periods. Cooperative base groups are longterm, stable groups with the additional aim of providing support, encouragement and assistance to members in order to achieve success [19].

However, pairing students will not automatically lead to successful cooperation $[25,26]$ and it is necessary to put measures in place to ensure that all members contribute equally [27]. According to Johnson et al. [19, p. 1:14], "For cooperation to work well, you explicitly have to structure five essential elements in each lesson" and "They are a regimen, [which] if followed rigorously, will produce the conditions for effective cooperation" [19, p. 6:7]. These five essential elements will now be discussed.

### 2.1 Positive interdependence

Positive interdependence is the most important element of CL [8, 19], and exists if an individual group member cannot succeed unless everybody else in the group also succeeds [19]. Felder and Brent [25] emphasise the interdependence aspect, when they state that everyone in the group must do their part, otherwise everyone else in the group will suffer the consequences. Stated in positive terms, this means the success and achievement of each team member is to the benefit of the other team members. It is therefore a 'win-win' situation. In a competition, where there are winners and losers, a 'win-lose' situation (negative interdependence) exists [8].

Positive interdependence can be structured in several ways [19]. There can be a single group product or specific common goals, which typically cannot be accomplished by an individual. The group can be rewarded for successful group work as well as for the achievement of individual members, for instance giving bonus points to the group if all group members achieve a certain grade or if the average grade for the group exceeds a specific minimum. Specific tasks and resources can be
allocated to specific individuals. Each individual's efforts are then necessary and indispensable for group success. Group cohesion can be enhanced by letting the group work together in the same place at the same time.

### 2.2 Face-to-face promotive interaction

Students must help each other succeed [19]. At first, students may find doing this difficult. Bellamy, Evans, Linder, McNeill and Raupp [28] observe that some students may consider working together as cheating, and students who are used to individual learning will be more concerned about their own performance than about that of their teammates.
According to Johnson and Johnson [29, p89], "the type of interdependence structured in a situation determines how individuals interact . . . positive interdependence tends to result in promotive interaction". The facilitator can further structure promotive interaction by getting students to discuss the problem and explain to each other the concepts and relevant strategies [8]. The facilitator should also monitor the groups and ensure that they interact and cooperate when solving problems [25]. In addition, students should be made aware and experience how explaining a problem to a teammate and discussing the solution improve their own understanding of the problem as well as their own problem solving skills [23].

### 2.3 Individual accountability/personal responsibility

While working in the group the individual has two obligations, of which the first is being committed to and contributing towards the success of the group [19]. This means coming prepared, being involved in and contributing to the problem solving process. Second, even while receiving help from others, students must ultimately take responsibility for their own learning and success. In a group, this means making sure they understand what is going on during the problem solving process and, if necessary, ask their partners, the assistant or the lecturer for clarification.

Keeping the group small (two people) means there is nowhere to hide, and this will encourage students to come prepared and to contribute. Giving individual tests is an important method to promote individual accountability [19, 24]. The result is that, while students learn together, each individual is still responsible for his/her own success.

### 2.4 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 [29]. These skills become more impor-
tant as the group size increases [19] or when the group stays together for an extended period of time and/or work on complex assignments [29]. Students must be taught these social skills [19] and as with other skills, must get the opportunity to exercise and develop them. Other skills include communication (learning to talk, learning to listen), trust building (getting rid of stereotypes, delegation) and decisionmaking and leadership (the ability to lead and to follow, compromise) [8].

### 2.5 Group processing

Groups should reflect on how they are doing as a group and how they can improve [19]. It is especially important for groups that meet several times before the completion of the assignment.

However, 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 [23]. Apart from feedback from the team members, feedback can also be supplied by the facilitator and then be discussed by the group.

## 3. Research method

### 3.1 Design

In line with Creswell [30] and as the aim of this research was to address an actual problem in an educational setting, namely the difficulty students had with mastering Thermodynamics, we decided to use practical action research as design. According to Schmuck [31], action research assists educators to collect data on their own practice in an objective manner, and at the same time, obtain solutions to problems and challenges in the classroom.

We implemented the CL intervention at two distinct South African universities presenting fouryear degree courses in engineering. Both universities have faculties spanning a wide spectrum-from Arts and Social Sciences to 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 programmes in these faculties. The engineering qualifications 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.

### 3.2 Population

The population comprised the students taking their first course in Mechanical Engineering Thermodynamics. At University A, Thermodynamics is taken
by the Process and Mechanical Engineering students. Attendance of the tutorials was compulsory, except for students repeating the subject. In total, almost 300 students attended the tutorials. The group was divided into an Afrikaans-speaking and an English-speaking group, and these groups were of almost equal size. Of the Afrikaans group, $97 \%$ were white and $18 \%$ were female students. The English-speaking group was ethnically more diverse, and there were $13 \%$ female students of whom $94 \%$ were white. Of the male students, $73 \%$ were white. The groups were lectured separately (by two resident lecturers) and also did the tutorials separately. The English tutorial was supervised by the group's lecturer and the Afrikaans tutorial, by the first author of this article. Each lecturer was assisted by three post-graduate students. The assistants rotated between assisting at the tutorials and marking the tutorial problems.

At University B, 230 Mechanical Engineering students enrolled for the course of which approximately 70 repeated the subject. More than $95 \%$ of these students were white and $12 \%$ were females. Lectures were presented in Afrikaans with whisper translation available to the few English-speaking students. Attendance of the tutorial was not compulsory but on average 120 students attended. The first author of this article presented the lectures and supervised the tutorials with the help of one assistant.

At both universities, there were three conventional lecture sessions in the morning on three different days of the week and a single tutorial session one afternoon per week. The procedure discussed here was implemented during the tutorial sessions.

At both universities, the students are introduced to the fundamental concepts and the first and second laws are covered. At University A, thermodynamics cycles are also covered, while at University B , thermodynamics cycles are covered in another course. Thermodynamic cycles are an application of the fundamental concepts and no new fundamental concepts are introduced.

### 3.3 Measuring instruments and data analysis

During the last tutorial of the semester, the students were asked to complete a questionnaire containing 17 statements relating to their experience of CPPS as implemented during the tutorials. Their responses could vary between 1 and 4 on a Likert-type scale. The teaching assistants as well as the resident lecturer at University A were also asked to fill in a questionnaire with a number of open-ended questions. They were asked to share their observations of the students during the tutorial as well as to give their opinion of the procedure. The ten assistants at

University A were all post-graduate engineering students who recently did the Thermodynamics course. At University B, there was only one assistant, in his final year of study. The assistants were therefore familiar with the subject matter, the situation and dynamics during tutorials and therefore trustworthy observers. The responses to the questionnaires were analysed for themes related to the five principles of CL.

As validation, at University B, external observers (one the co-author of this article and the other from the academic support department, both with PhDs in Education) attended tutorial sessions and shared their observations of the activity during the tutorial sessions. The first author kept a journal of the implementation of the procedure at both universities. Both the journal and the comments of the external observers were analysed and correlated with the themes from the questionnaires.

## 4. Implementation

CPPS was implemented at University A during the first semester of 2013, and at University B, during the second semester of 2013.

From the literature, it was clear that it was necessary to make a conscious effort to obtain student 'buy-in' [10, 26, 32]. Therefore, during the first meeting with the students, the strategy was explained as well as the rationale behind it.

### 4.1 Group formation

Felder and Woods [24] as well as Oakley and Felder [26] 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 each will be discussed in some detail.

As attendance was compulsory at University A, we had a very good idea of how many students to expect. As the students entered the class, two assistants handed each a small piece of paper with the number of the seat where they were supposed to sit. The seat numbers were randomly distributed throughout the whole lecture hall. The lecture hall was big enough to have an open seat throughout between students. After a few tutorials, we found that more and more students ignored the seat number and sat with friends. If the student who was supposed to sit in that seat showed up, he/she was merely told to find another seat. That caused the system to degenerate.

We then decided to fill up the class from the front. To retain some measure of randomness the seat numbers indicated on the pieces of paper were not
sequential. The even numbers in the row were first handed out, and then the uneven numbers. As there was a pattern, it was easier to spot students who were not sticking to their seat numbers.

At University B, attendance was voluntary, and we therefore did not know how many students to expect. As the students entered the class, each received a paper with a test (see discussion later). On the test a seat number was displayed. The class had two doors and two people were necessary to hand out the tests. The class was filled from the front, row by row. The even seat numbers were handed out at one door and the uneven numbers at the other. Again, there were individuals who ignored the seat numbers and sat with friends. Although it was possible, we found that it was not practical to check whether students sat in their allocated seats.

Finally, we used a laptop computer and a student card reader 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 could correlate on a personal computer the allocated seats with the names on the tests that the pairs handed in afterwards. Students who did not sit in their allocated places did not receive any credit. Once the students realised this, they accepted the arrangement.

### 4.2 Individual test, social and teamwork skills

In order to encourage students to come prepared and accept individual accountability, students wrote an individual test at the beginning of the tutorial. The tests lasted $10-15$ minutes and covered the content they had to prepare for the tutorial. After the tests had been handed in, it was discussed with the class and then marked by the assistants.
In line with the recommendation that students need to be taught teamwork skills, a specific skill was then briefly discussed.

### 4.3 Solving a problem together

After the discussion, the students formed pairs-the seat numbers were allocated in such a way that it was obvious who had to work together-and the tutorial problems handed out, one problem set per pair.

At both universities, in order to promote positive interdependence, the problems were made challenging, typically the type of problems they could expect in the final assessment. In addition, they had to complete the problems in a limited time. They had to hand in one answer sheet per pair and received the same mark for their joint effort. Students were also encouraged to divide the different activities and tasks between them: let one student read the problem out loud while the other present
the problem graphically; let one handle the calculator and the other look up values in the tables, etc.

By raising their hands, a group could indicate that they needed the assistance of the lecturer or one of the assistants. If it became clear from the questions they asked, that there were several who struggled with the same problem, it was explained to the whole class-usually on the board.

At University A, when a pair completed the problems, they handed in their calculations and were free to go. Their answers were marked by the assistants and the students could collect the marked papers afterwards. The points obtained for the individual test and the problems completed in pairs contributed $15 \%$ towards their semester mark. The questions, key equations and answers for the test and tutorial problems were made available on the course website.

At University B, students submitted their answers by mobile phone on a dedicated website during the tutorial. When most or all students were done, the website was closed. In order to introduce group processing, the problems were discussed and explained on the board, and the groups graded their own efforts. They filled in their names, final answers and final marks on the problem sheet and handed it in as they left. The answers on the website were also available as a spreadsheet and were marked by the assistant. The average of the accumulated points for all the individual tests and tutorial problems was added as a $5 \%$ bonus to the semester mark. The tutorial problems and the final answers were made available on the course website.

As a form of group processing, the students were encouraged to show their excitement when solving a problem and to thank each other for their help and assistance at the end of the session.

## 5. Results and discussion

There was almost universal agreement amongst the assistants, lecturers and observers that CPPS (initi-
ally referred to as PPS [Paired Problem Solving]) leads to productive tutorials. One assistant with several years' experience as assistant during tutorials wrote, "I think PPS is excellent" and ". . . this was the most focused tutorial I have ever been in, both as a student and an assistant". Another said it was a "fantastic idea". The lecturer of the English group at University A wrote, "In my opinion a good system . . . Will try to win other lecturers over to this method." One of the ten assistants at University A felt that CPPS would be better for bigger tasks, "It would work better in modules where you apply the PPS system to do projects/reports/assignments together."
The way the students experienced the tutorials were reflected in their responses to the 17 statements on the questionnaire. Their responses could vary from "Do not agree at all" (1) to "Fully agree" (4). The statements were grouped into factors. Some of these factors could be linked directly to one the principles of CL. The four questions that correlated well with the factor "Positive Interdependence" are shown in Table 1. The correlation coefficient (CC) for each question with the factor, the average and standard deviation (SD) for each question as well as the statistics for the factor for each university are also shown.
For this factor, the Cronbach alpha was 0.796 and the mean inter-term correlation, 0.496 , which indicates a very high level of internal consistency for these questions.
The factor average of 2.82 for University B indicates that the students essentially agreed that positive interdependence resulted at University B. The average value at University A was significantly lower (effect size 0.7) but still above 2. Attendance of the tutorials at this university is compulsory, and it is possible that students who would rather work alone, were now forced to work with somebody, while others did not mind, leading to the relatively high standard deviation. In spite of this, it almost invariably happened at both universities that upon

Table 1. The existence of positive interdependence between partners

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

Table 2. Face-to-face promotive interaction-an indication of constructive working relationships in the groups

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

receiving the problem statement, students turned towards each other and started working on the problem. An attitude of 'we' instead of 'me' was evident in most groups, which was encouraging because other research have found that it can easily happen that one student does all the work [18]. Five questions that correlated well with the factor "Face-to-Face Promotive Interaction" are shown in Table 2. For the calculation of the statistics of this factor, we reversed the scores of Questions 3 and 17.
The Cronbach alpha for this factor was 0.67 and the mean interterm correlation, 0.30 .

The high averages for this factor $(\bar{x}=3.06 ; 3.20)$ are indicative of the fact that students at both universities helped each other and that effective working relationships existed in the group. This was echoed in the comments from several of the assistants. "There was much discussion amongst students regarding the work and less socialising!" Also, when "two good students were paired, they challenged each other and had very good and in depth questions for the assistants often beyond the scope of the work." When two weak students were paired, they spent "lots of time figuring things out and in so doing gained a lot from each tutorial". This was confirmed by one of the observers, "I was
amazed at how well they cooperated". Furthermore, after an aspect students had been struggling with was explained on the board, "intense discussion took place" presumably to gain clarity on what had been said.

Because the two students work together for only one afternoon, at a defined location and time, on a well-defined task, the potential for interpersonal conflict and disagreement was greatly reduced and it seems almost all students possessed sufficient social skills to cooperate effectively.
However, not all pairs cooperated successfully. One of the assistants at University A remarked, "In some cases where a stronger student was paired with a weak student the work would be dominated by the stronger student and the weaker student would only act as a scribe" or "merely tagged along."

Writing the individual test at the beginning of the tutorial deviated from the established practice at University A to have the test at the end of the tutorial. The test could therefore have increased the stress felt by some students, and several complained about having to write the test at the beginning.

Three questions correlated well with the factor "Personal responsibility" and are shown in Table 3.

For this factor, the Cronbach alpha was 0.64 and the mean interterm correlation, 0.376 .

Table 3. The extent to which students felt personally responsible

|  |  |  | Average/SD |  |
| :---: | :---: | :---: | :---: | :---: |
| No | STATEMENT | CC | A | B |
| 10 | During PPS my contribution was necessary for the group to be successful. | 0.689 | $\begin{aligned} & 2.91 \\ & 0.70 \end{aligned}$ | $\begin{aligned} & 2.98 \\ & 0.58 \end{aligned}$ |
| 4 | During PPS I could use my unique abilities to the advantage of the group. | 0.475 | $\begin{aligned} & 2.66 \\ & 0.79 \end{aligned}$ | $\begin{aligned} & 2.87 \\ & 0.64 \end{aligned}$ |
| 11 | During PPS I felt a sense of responsibility towards my group. | 0.464 | $\begin{aligned} & 2.95 \\ & 0.80 \end{aligned}$ | $\begin{aligned} & 3.11 \\ & 0.69 \end{aligned}$ |
| Factor |  |  | $\begin{aligned} & 2.84 \\ & 0.59 \end{aligned}$ | $\begin{aligned} & 2.99 \\ & 0.47 \end{aligned}$ |

The average for this factor indicated that the students at both universities essentially agreed that they felt a sense of responsibility towards the group. The test at the beginning of the tutorial also encouraged students to come better prepared as the mark contributed to the semester mark. Several students at University A remarked that they spent a lot of time preparing for these tests.

One of the assistants at University A remarked, "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." It is clear that working with a stranger reduced socialising and making small talk. He continued, "The quality of the tutorials degenerated as the students continued to sit in their friendship groups and correspondingly spent less time actually working and more time chatting."

At University B, the attendance of the tutorials increased dramatically. In previous years, there would be between ten and twenty students attending a tutorial. With the implementation of CPPS, this rose to well over one hundred. However, there could have been other contributing factors. In previous years, the students all did the prescribed problems in the study guide during the tutorial. Normally, these problems stayed essentially the same from year to year. It is possible that in previous years, students preferred to attempt these problems in their own time, using solutions obtained from students who had already completed the course, instead of attending the tutorials. With CPPS, the tutorial problems were new. Another possible reason could be the fact that with CPPS, attendance was now recorded and a maximum of $5 \%$ bonus points could be earned. This was not the case in previous years. This may not seem much, but for a borderline student, $5 \%$ may make the difference between getting admission to sit for an examination and not being able to sit for the examination.

Generally, students stayed together until the problem was solved. At University A, they handed in the completed problem and were then free to go. It would therefore have been easy for one student to leave before the problems were finished. At Uni-
versity B, pairs graded their own work and if individual students wanted to leave early, their names were noted and they did not receive any credit. During the course of the semester, only a few students left early-usually for a doctor's appointment or something equally important.

At both universities, there were individual midterm and end-of-term examinations, which ensured that students were still individually held accountable for their own learning.
Two questions related to the social advantages due to CPPS correlated well, and these are shown in Table 4.
For this factor, the Cronbach alpha was 0.69 and the mean interterm correlation, 0.53 .

Although the average for the factor was low, it seemed that students at University B felt that CPPS taught them to cooperate better with other people. Fortunately, as the task was simple ("Solve the problem"), there were only two people involved and they only stayed together for the afternoon; the interaction was therefore less complicated. This was confirmed by the responses from the assistants, "Generally they seemed to get along well" and "They could all work together well enough to get the tutorial done." This was further confirmed by the low score for statement 3 ("Conflict regularly occurred during CPPS") in Table 2. At University A, one respondent noted a "much more positive atmosphere in class". One of the observers remarked, "generally their body language indicated that they were comfortable in their cooperation". Students seemed to appreciate the practical advice on cooperation before the problems were handed out.

At University B, pairs marked their own work and this allowed them to reflect on the approach they followed in solving the problems.
Three questions correlated with a factor we called "Synergy", and these are shown in Table 5.
The Cronbach alpha for this factor was 0.56 , and the mean interterm correlation, 0.298 .
The slightly lower averages at both universities indicated that the students essentially agreed that both team members found benefit from working

Table 4. The social benefits of working together

|  |  |  | Average/SD |  |
| :--- | :--- | :--- | :--- | :--- |
| No | STATEMENT | CC | A | B |
| 6 | PPS taught me to cooperate better with other people. | 0.867 | 2.55 | 2.72 |
|  |  |  | 0.91 | 0.90 |
| 16 | PPS helped me to fit in socially. | 0.743 | 1.83 | 2.12 |
|  |  |  | 0.91 | 0.91 |
| Factor |  | 2.03 | 2.07 |  |
|  |  | 0.68 | 0.70 |  |

Table 5. Synergy in group work

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

together. The low average for Question 7 was especially encouraging.

## 6. Conclusions

CPPS is a well-structured strategy for problem solving tutorials that can be used for large tutorial classes. It was evaluated during an introductory Thermodynamics course and resulted in active collaboration between students. Taking the feedback of the assistants, observers and lecturers as well as the feedback from the students into consideration, we are satisfied that the elements of CL were sufficiently structured into CPPS:

- The procedure followed during the tutorials ensured positive interdependence.
- The majority of students engaged in promotive interaction and took responsibility to complete the task at hand.
- The individual test at the beginning of the tutorial and the individual mid-term and final examinations ensured individual accountability.
- It seemed almost all students possessed sufficient social skills to cooperate effectively.
- Having pairs mark their own solutions gave students ample opportunity to reflect on their problem solving strategy and how they could have done it differently.

The results need to be interpreted in the light of the following limitations. The procedure was implemented and the results obtained in an introductory Thermodynamics course where students had to solve well-defined problems. CPPS can most probably also be implemented with the same results in tutorials of other engineering science or even natural science courses where students need to solve well-defined problems. However, CPPS has not been evaluated in situations where students had to solve ill-defined or design problems.

The study was conducted at two South African universities. Although one of the three groups was ethnically diverse, the majority of students were
white males. We did not investigate the possible effect of gender and ethnicity on the implementation of CPPS. It is possible that in environments where ethnicity and gender have a significant effect, results may be different.

At both universities, while students sometimes work in groups, individual learning dominates. The students were therefore unfamiliar with many of the concepts of CL. We are convinced that familiarity with and positive prior experiences of CL will have a positive effect on the implementation and outcomes of CPPS.
The effect of giving students some sort of freedom to choose their partners was not investigated. In literature, a strong case is made for not allowing students to choose their own partners and, as mentioned previously, we found that sitting with friends often led to reduced focus on the task at hand. However, despite our best efforts to motivate the random allocation of partners, it seemed there were always individuals who did not like this arrangement and who kept looking for loopholes in the system. While there are risks, there may also be advantages to searching for a more accommodating group formation procedure.
Although this study only focused on the implementation of CPPS with the inclusion of the five elements of CL and the experiences of students and facilitators with regard to the implementation, we still intend to investigate the effect of CPPS on academic performance and concept retention of students, which would add value to the proposed CPPS strategy.

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## References

1. A. S. Blicblau and H. van der Walt, Strategies for progressing through engineering, SEFI 36th Annual Conference, Aalborg, 2008.
2. M. Ishida and C. Chuang, New approach to thermodynamics, Energy Conversion and Management, 38(15-17), 1997, pp. 1543-1555.
3. C. Borgnakke and R. E. Sonntag, Fundamentals of thermodynamics, 7th edn, Wiley, Hoboken, N.J., 2009.
4. Y. A. Cengel and M. A. Boles, Thermodynamics: An engineering approach, 6th edn, McGraw-Hill, 2007.
5. J. C. Perrenet, P. A. J. Bonthuijs and J. G. M. M. Smits, The suitability of problem-based learning for engineering education: Theory and practice, Teaching in Higher Education, 5(3), 2000, pp. 345-358.
6. R. M. Felder and R. Brent, Understanding student differences, Journal of Engineering Education, 94(1), 2005, pp. 5772.
7. J. E. Mills and D. F. Treagust, Engineering education: Is problem-based or project-based learning the answer?, Australasian Journal of Engineering Education, 3, 2003, pp. 2-16.
8. K. A. Smith, S. D. Sheppard, D. W. Johnson and R. T. Johnson, Pedagogies of engagement: Classroom-based practices, Journal of Engineering Education, 94(1), 2005, pp. 87101.
9. C. C. Bonwell, Active learning: Creating excitement in the classroom, J. A. Eison (ed), School of Education and Human Development, George Washington University, Washington, DC, 1991.
10. H. Detloff, Experiments in cooperative learning: Successes of an engineering novice, 30th ASEE/IEEE Frontiers in Education Conference, Missouri, 2000.
11. A. Karimi and R. D. Manteufel, Assessment of student knowledge in an introductory thermodynamics course, ASEE Annual Conference and Exposition, San Antonio, Texas, 2012.
12. Center for Teaching and Learning, What is active learning?, 2013, http://www1.umn.edu/ohr/teachlearn/tutorials/active/ what/index.html, Accessed 15 January 2013.
13. R. M. Felder and R. Brent, Active learning: An introduction, ASQ Higher Education Brief, 2(4), 2009, pp. 1-5.
14. R. M. Felder and R. Brent, Learning by doing, Chemical Engineering Education, 37(4), 2003, pp. 282-283.
15. R. M. Felder, Sermons for grumpy campers, Chemical Engineering Education, 41(3), 2007, pp. 183.
16. L. Williams and R. Kessler, Pair programming illuminated, Addison-Wesley, Place, 2003.
17. L. Williams and R. L. Upchurch, In support of student pair-
programming, 32nd SIGCSE technical symposium on Computer Science Education, New York, 2001, pp. 327-331 .
18. E. Mentz, J. L. van der Walt and L. Goosen, The effect of incorporating cooperative learning principles in pair programming for student teachers, Computer Science Education, 18(4), 2008, pp. 247-260.
19. D. W. Johnson, R. T. Johnson and E. Johnson-Holubec, Cooperation in the classroom, 8th edn, Interaction Book Company, Halifax, 2008.
20. M. J. Prince, Does active learning work? A review of the research, Journal of Engineering Education, 93(3), 2004, pp. 223-229.
21. M. Goos, P. Galbraith and P. Renshaw, Socially mediated metacognition: Creating collaborative zones of proximal development in small group problem solving, Educational Studies in Mathematics, 49(2), 2002, pp. 193-223.
22. P. Heller and M. Hollabaugh, Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups, American Journal of Physics, 60(7), 1992, pp. 637-644.
23. A. Whimbey, J. Lochhead and R. Narode, Problem solving and comprehension, 7th edn, Routledge, New York, 2013.
24. R. M. Felder, D. R. Woods, J. E. Stice and A. Rugarcia, The future of engineering education II: Teaching methods that work, Chemical Engineering Education, 34(1), 2000, pp. 2639.
25. R. M. Felder and R. Brent, Cooperative learning in technical courses: Procedures, Pitfalls and Payoffs, ERIC Document Reproduction Service ED 377038, 1994.
26. B. Oakley, R. M. Felder, R. Brent and I. Elhajj, Turning student groups into effective teams, Journal of Student Centered Learning, 2(1), 2004, pp. 9-34.
27. M. Arevalillo-Herráez and J. M. Claver, Assessment technique to encourage cooperative learning in a computer programming course, International Journal of Engineering Education, 27(4, Part II), 2011, pp. 867-874.
28. L. Bellamy, D. Evans, D. Linder, B. McNeill and G. Raupp, Teams in engineering education, ERIC Clearinghouse, 1994.
29. D. W. Johnson and R. T. Johnson, Joining together: Group theory and group skills, 11th edn, Pearson, 2013.
30. J. W. Creswell, Educational research: Planning, conducting and evaluating quantitative and qualitative research, 3 rd edn, Pearson, 2008.
31. R. A. Schmuck, Practical action research for change, 2 nd edn, Corwin Press, 2006.
32. S. Ledlow, J. White-Taylor and D. L. Evans, Active/Cooperative learning: A discipline-specific resource for engineering education, American Society for Engineering Education Annual Conference \& Exposition, 2002.

Wilhelm Marinus Kalmijn van Niekerk obtained his B. Eng. (Chem) in 1979 and his M. Eng. (Chem) in 1991 from the University of Pretoria, South Africa. He worked in the coal-to-liquid petrochemical industry for six years before becoming a lecturer at the Department of Chemical Engineering at the University of Pretoria in 1986. He started lecturing at the Department of Mechanical Engineering at Potchefstroom in 1995. He lectures both undergraduate and the post-graduate Thermodynamics courses for Mechanical Engineering students as well as the Thermodynamics bridging course for students who want to do the post-graduate degree in nuclear engineering. He has published in the fields of solar energy, community development and engineering education. He is a registered professional engineer and a member of South African Institute of Chemical Engineers and the Solar Energy Society of South Africa.

Elsa Mentz obtained her B.A. in 1980, her M.Sc. in 1997 her and Ph.D. in 2001 from the Potchefstroom University for Christian Higher Education. She started her professional career as a high school Mathematics teacher and has been involved with teacher training for the past 25 years. She is director of the Research Focus Area: Self-Directed Learning, in the Faculty of Education Sciences at North-West University, South Africa. As professor in Computer Science education, her passion is education and specifically the study of teaching-learning strategies for effective teaching to promote selfdirected learning among students. She has published both nationally and internationally on the topics of pair programming and cooperative learning.

