The development of a cooperative teaching-learning strategy for engineering thermodynamics

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Mechanical Engineering Thermodynamics is often seen as difficult and the pass rates are often lower than the other engineering modules presented during the same semester. In an effort to improve this situation, we decided to implement a cooperative teaching-learning strategy, Paired Problem Solving (PPS) in the Thermodynamics classes. This strategy is based on the principles of Pair Programming, a strategy that has been used with success in the teaching of computer programming. We decided on an action research approach to enable us to use an iterative process with a cycle of design, implementation, evaluation and revision of this specific strategy. Qualitative and quantitative research methods were used. In the first semester of 2011, we compared the results achieved by students in five End-of-Chapter Tests doing the test in pairs with the results of those completing it individually. Although there was no significant difference, from questionnaires and interviews it was clear that students were very positive about PPS. In the second semester of 2011, encouraged by the positive results, we increased the cooperative learning component. As students entered class for a PPS session, they formed groups of two and then had to solve a problem together. This invariably led to activity and interaction between team members. From questionnaires and interviews, it was clear that these students were also positive about PPS. The pass rate also improved significantly. However, its implementation required a substantial additional effort. In this paper, we describe our experience with, results of and lessons learned during the implementation PPS in Engineering Thermodynamics during the second semester of 2011.

Introduction

Thermodynamics is an integral part of any Mechanical Engineering curriculum. At the university where this study is conducted, students have to take two Thermodynamics modules. The teaching strategy is lectures in the mornings and one tutorial session per week in the afternoon. During the tutorial students have to solve a number of prescribed problems – normally on their own. In tests and exams they have to demonstrate their understanding of the principles by again solving a number of problems. The pass rates in the Thermodynamics modules are generally low compared to other modules during the same semester and Thermodynamics has built a reputation as a difficult module.

Thermodynamics is also seen as difficult at other universities. (Baher, 1998; Blickbau & van der Walt., 2008; Ishida & Chuang, 1997). The reasons why it may be difficult are not systematically investigated. Blickbau and van der Walt (2008) mention that concepts such as entropy are difficult to grasp. Heller, Keith and Anderson (1992:627) notes that some students consider problem solving and conceptual understanding to be independent of each other: "I understand the material but just can't solve the problems" or "I can do the problems in the textbook but your test problems are different." Students need to understand the concepts when they apply their problem solving skills (Mettes, Pilot, Roossink & Kramer-Pals, 1980).

While lectures may be appropriate for the provision of up-to-date information, (McKeachie, 1994), they are not particularly effective for teaching problem-solving skills. (Johnson 1999; Felder & Brent, 2003). In the teaching of computer programming, a successful collaborative programming approach, namely pair programming (Williams, Kessler, Cunningham & Jeffries, 2000), was developed. In pair programming, two programmers work side by side at the same computer, execute the programming task together and collaborate on the same design, algorithm and code (Williams & Upchurch, 2001). It draws on the principles of Pair Problem Solving (PPS) as introduced by Whimbey and Lochhead (1980). Mentz, van der Walt and Goosen (2008) suggested that cooperative learning principles should be incorporated into pair programming to make it a more effective teaching/learning strategy. Both Thermodynamics and computer programming rely on the application of logic and the development of a "solution strategy" (Deek, Hiltz, Kimmel & Rotter, 1999:317) to solve a wide variety of problems.

We therefore decided to implement PPS in the Thermodynamics classes. In the implementation of PPS we tried to adhere to the five principles for effective co-operative learning (Johnson & Johnson, 2009). We hoped that a modest additional effort could result in significant improvement in teaching efficiency. We decided on an action research approach to enable us to use an iterative process with a cycle of design, implementation, evaluation and revision of this specific strategy. Qualitative and quantitative research methods were used.

During the first semester of 2011, we randomly divided the class into a PPS and a control group. The PPS group completed five End-of-Chapter class tests in groups of two while the control group completed the tests individually. The students filled in a questionnaire before and after the completion of the class tests and six students were interviewed to determine their experiences of working in pairs.

Although there were no significant differences in the semester test results between the two groups, it was clear from the interviews and questionnaires that the students are very positive about PPS. They felt working in pairs helped them to understand the work better. Eighty-seven per cent indicated that they would like to work in pairs again. We reported on this study at the SASEE Conference in 2011 (van Niekerk, Mentz & Smit, 2011).

In the second semester of 2011, we adopted our approach to increase the cooperative learning component. In this paper we report on the results of this study.

Theoretical background

Passive vs active learning

Jack Lochhead wrote in 1985 (Lochhead, 1985:109):

> Traditionally we have attributed academic success to innate intelligence and hard work. From this perspective teachers have two responsibilities; to motivate students to work, and to present material clearly so that it can be grasped by some of the less clever students.

He continues to say that a third factor may also be critical: the beliefs students hold about learning. He thinks that it is common that students believe they can understand a subject by "copying" the content into their memories: "Poor problem solvers are less active because they do not believe there is anything for them to do. …. They think you either know the answer to a question or you do not." (Lochhead, 1985:110).

The lecturer is the active party presenting the material, and the student the passive party – passive in the sense of merely copying and memorizing the material. This pattern has led to a robust culture which seems to be dominant – even today. The traditional lecture is probably the most common instructional strategy students have been exposed to in high school (Ledlow, 2002). The passive attitude under students leads to complaints about the lack of "worked out" problems (Detloff, 2000) – which has also been our experience. Karimi and Manteufel (2012) complain that students increasingly get hold of solution manuals for the End-of-Chapter problems in textbooks from the internet. At this university, it is common to find students with a neatly copied and bound set of "memorandums" for the tutorial problems and previous exams –

often containing faulty solutions.

Richard Felder and Rebecca Brent have done much work in promoting active learning as a method for enhancing the effectiveness of teaching (Felder & Brent, 2012, 2009, 2008). Prince (2004) found all forms of active learning beneficial to students, although the results vary in strength. Hake (1998) found that interactive-engagement methods increased the conceptual understanding and problem-solving ability of students in physics courses.

Active learning uses one or more of the following strategies (Center for teaching and learning, 2013): talking and listening; writing; reading and reflecting. Four broad categories are identified: individual activities; paired activities; informal small groups and cooperative student projects.

Pair Problem solving

Pair Problem Solving is a method for making students more active (and efficient) learners (Lochhead, 1985). Each member of the pair has a distinct and well-defined role. The "Problem solver" reads and thinks aloud while the "Listener" (a) checks every step of the solution as it is developing, making sure he/she understands what is being done and points out any uncertainties or errors and (b) demands constant vocalization by the Problem Solver. Thinking aloud is crucial in the process. Solving the problem step by step and explaining every step in detail, contribute to the understanding of the process (Mentz, Breed & Havenga, 2013). The role of the teacher now changes to that of a facilitator, making sure that the students play the roles they are supposed to, encouraging them to think about different ways to solve the same problem and allowing them to select the best approach.

The rationale behind Pair Problem Solving is that the ability to solve problems is a skill and a skill cannot be mastered passively. According to Felder and Brent (2003) a skill is mastered by practicing while Lochhead (1985) distinguishes two steps in mastering a skill:

a) The skill is demonstrated by an expert problem solver.
b) The skill is performed by the student and feedback is given while the skill is being performed.

Thermodynamic textbooks usually explain to students how to solve problems in a systemic and orderly manner (Anderson, 1994; Borgnakke & Sonntag, 2009; Cengel & Boles, 2007; Moran & Shapiro, 1995). It is also reasonable to expect that lecturers will demonstrate how to solve some problems on the board. Students should therefore have sufficient examples of how to solve problems. But now they need to develop their own ability. The problem with analysing a complex problem is that it is usually a silent process which takes place inside a problem solver's head. Therefore vocalization is important to make the process "visible" and to provide feedback. During this process, students get the opportunity to develop their own unique style.

The constructivists' demand that students must generate their own knowledge is applied in a new way: Instead of focussing on content, the focus is now on a skill. Instead of trying to memorize as many as possible problems and their solutions, students develop their skill as problem solvers.

In a later paper, Lochhead and Whimbey (1987) discuss Thinking Aloud Pair Problem Solving (TAPPS) which seems to be essentially the same as their Pair Problem Solving. Felder and Brent (2003:283) refer to TAPPS as "arguably the most powerful classroom instructional technique for promoting understanding." He also mentions *think-pair-share* in which students work on something individually and then compare their responses before being called upon by the lecturer. The University of the Witwatersrand organized a workshop in 2008 where Felder and Brent (2008) addressed active learning. Participants could experience first-hand the advantages of working in groups of two.

Bonwell and Eison (1991) refer to high-risk and low-risk strategies for the implementation of active learning and state that all barriers can be overcome by careful planning. Our experience was that students are often reluctant to form pairs during a lecture and if they are already a group of three or four, to break up the group.

It was decided to include the principles of cooperative learning during the implementation of PPS in Thermodynamics.

Cooperative learning

Johnson and Johnson (2009) describe five essential elements that must be adhered to for successful co-operative learning (CL) (Smith, Sheppard, Johnson & Johnson, 2005).

Positive interdependence. Students must believe that the success of each team member is dependent on the success of each of the other team members. “I cannot succeed if you do not succeed as well.” Positive interdependence can be structured in a variety of ways.

Promotive face-to-face interaction. Students must interact in such a way as to ensure that each team member reaches the goal. The better the structures to ensure positive interdependence, the easier promotive interaction will take place, but it is still necessary to monitor the interaction in the group and take corrective action if necessary.

Individual accountability / Personal responsibility. Each student must accept responsibility and be held accountable for his/her contribution towards the success of the group (which is tied to his/her own success).

Social skills refer to the application of interpersonal and small-group skills in order to get to know and trust each other. Students need to communicate with each other and learn to listen and respect each other’s viewpoints and initiatives.

Group processing means that after completion of the task, the group should reflect on how well they performed as a group, what they could improve on in future and what worked well.

Design and methodology

Research design

As the aim of this research was to address an actual problem in an educational setting with a view to improving students’ learning and our professional performance, we decided to use practical action research (Creswell, 2008) as the design. This article reports on the second iteration of this action research process.

Method

We applied quantitative as well as qualitative research methods in order to obtain a clear picture of the focus of our research.

Population

The study was performed using the 180 second-year Mechanical Engineering students enrolled for the first of two modules in Mechanical Engineering Thermodynamics in the second semester of 2011.

Measuring instruments

At the end of the semester we asked the students to complete a semi-structured questionnaire on their perception of PPS. To strengthen our data and to determine their experiences of working in pairs, semi-structured interviews were also conducted after completion of the module with six randomly selected students. We were satisfied that we had reached data saturation.

Statistical techniques and data analysis

The questionnaires were analysed by determining average on the responses of students.

For the qualitative analysis, the interviews were transcribed and data was analysed. Themes were identified from the analysis of the data which will be used in our discussion of the results. The data from the interviews were analysed by one of the authors and verified and cross-checked by the co-author.

Implementation

The first Thermodynamics module, taken by second-year students, is presented in the second semester. Four lecture periods were allocated to this module – a single period each on Monday and Tuesday mornings and the first two periods on a Friday. A tutorial was scheduled for the Wednesday afternoon.

The formal instruction component was decreased and the cooperative learning component increased. This was done in cycles lasting two weeks. A chapter was covered every two weeks. The first lecture period (on a Monday) was used to introduce the chapter content and give an overview of the concepts to be covered in the specific chapter. It was usually possible to show a video or animation to illustrate the concepts. The Tuesday period was not used for instruction. The students had to study on their own. Apart from the prescribed textbook, study notes and a study guide were available. The study guide contained the required outputs per chapter as well as the tutorial problems. The contents of the lecture notes were essentially the same as the contents of the lectures of previous years.

PPS tutorials were scheduled twice a week – on Wednesday and Friday. In order to make sure students came prepared, a short individual test was given before the tutorial commenced. After a few attempts this individual test was abandoned because it was not possible for a single person to properly invigilate 180 students.

Initially a seating plan was also worked out where each student was randomly allocated a seat. The goal was to prevent students to agree beforehand that one will prepare and the other one not. This was not effective. It could not be ensured that students were sitting at their allocated seats and we suspected that friends merely sat together regardless of the seating plan. Also not all students on the class list turned up and new pairs had to be formed. We had to keep track of the new pairs in order not to pair them again at the upcoming class. Finally students were allowed to form their own pairs.

Prescribed problems are given in the study guide. Initially, students were allowed to work through the prescribed problems for a while and then they were told to hand in one specific problem. This was not a good idea. Some students had copies of the solutions to the problems (obtained from students of previous years) and merely copied the answer or got the solution from someone else. Therefore, once they were all in pairs, we handed out a new problem. Once everybody had the problem description, the problem and a possible solution strategy was discussed. With complicated questions, some scaffolding as well as the final answer was provided. The answers were not graded. We stressed the fact that the goal was to understand the problem.

The individual test was moved to the Friday morning, replacing the second tutorial class. The goal of the individual test was to encourage students to take the PPS session of the previous Wednesday seriously – as preparation for this test – in line with the cooperative learning slogan of: “Work together but achieve alone”. The test was graded, handed back and discussed during the next contact session. Also, an overview was given of the work for the upcoming week.

During the next PPS tutorial, students were again given a problem to solve in pairs and on the last PPS tutorial of the two week cycle an “End-of-Chapter test” was given.

Results and discussion

All the students interviewed felt positive about solving problems in groups of two. They used expressions such as: *“I rather enjoyed the way we did it.”, “It works for me.”, “It helps a lot.”*

We tested the students’ experience with PPS in a questionnaire at the end of the semester. Their responses could vary between “Do not agree at all” (1) to “Fully agree” (4). There was substantial correlation (which indicates good reliability) between the questions shown in the table below.

Table 1. Questions relating to a positive experience.

No	Statement	Average
4	The PPS sessions helped me in my preparation for tests and exams.	2.8
7	The fact that I could work with someone, helped me to do the PPS problem.	2.9
13	I prefer the traditional approach with lectures and individual tutorials.	2.2
14	I prefer the approach followed in this module with an introductory session, PPS, small tests and End-of-Chapter Tests.	2.8
15	The lecturer should have done more examples on the board.	3.6
16	I would prefer to work in groups of two again next year in the second Thermo module	2.9

The positive experience of PPS is clear from the averages of Questions 4, 7, 14 and 16. We applied reversed scoring to questions 13 and 15 and determined Cronbach’s α as well as the mean inter-item correlation. A value of 0.76 was obtained for Cronbach’s α and the mean inter-term correlation was 0.35. These figures indicate a high level of internal consistency for these questions.

The correlation between Question 13 and 15 and the positive experience of PPS was negative with values of -0.61 and -0.66. This is an indication that the students who felt positive about PPS, did not feel strongly about the lecturer doing more problems on the board and following the traditional approach during lectures.

This positive sentiment is echoed in the open ended question at the end of the questionnaires. In response to the question: “If you could identify one aspect that worked well this year and should be retained for the next year, what would it be?” the aspect that was mentioned most (almost 40% of the responses) was that the cooperative problem-solving aspect should be retained. The second most common answer, with only 16% of the responses, was that the regular assessments should be retained.

It was also clear from observing the class during PPS sessions that students generally liked cooperating with one another. Almost without exception, after having read through the problem, they turned towards each other and started solving the problem in an active manner. The different tasks necessary to solve the problem (calculation, writing, looking up values in the tables, finding the relevant theory in the textbook) were equally divided between the two members – with interaction taking place all the time.

Two themes that shed some light on the reasons for the students being positive about working together emerged from the interviews:

a. Getting rid of the feeling of uncertainty during problem solving.
b. The development of problem-solving skills

They found comfort in working with a fellow student:*"….you has that assurance of someone next to you, who see what you are doing and if you are doing it right."* If one does not know how to proceed or does not understand a certain aspect, chances are that one's partner will. If neither of them knows, at least they can discuss a possible solution. They also feel more at liberty to profess their ignorance or put a question to the fellow student than to the lecturer. The feeling is that "two heads are better than one".

Furthermore, it was clear that they also found assurance in being able to obtain solutions to problems they could refer to later. *"If you have worked through it, you can recognize it and knows what to do."* They seem to be comfortable with rote learning as a tried and tested strategy. Although they realize that it has its limitations in some Engineering disciplines such as Thermodynamics, it seems that it will be their instinctive approach.

They also felt that working with someone else exposed them to alternative problem solution strategies and that it helped them in developing their own problem-solving skills. Being confronted with another viewpoint *"forces one to think"* and it created a new way of thinking. Working from first principles is different from the strategy they followed at school, which they know and are comfortable with. It is clear that they realize that the better approach to this module is to develop one's own problem solving skills, instead of following "recipes".

Questions 1, 2, 8 and 11 also had substantial correlation and are shown in Table 2 below.

Table 2. Questions testing activity.

No	**Statement**	Average
1	The fact that I had to study for the small tests helped me in my preparation for tests and exams.	3.1
2	The fact that I had to study for the End-of-Chapter Tests helped me in my preparation for tests and exams.	3.5
8	The fact that the lecturer provided the answers to the intermediate steps helped me to do the PPS problem	2.7
11	The fact that it was "open book" helped me to do the PPS problem	3.1

Questions 8 and 11 relate to the activity during the PPS session and the goal of the small tests and the End-of-Chapter-Tests was to encourage students to take the PPS session seriously. Cronbach's α for this group of questions was 0.61 and the mean inter-term correlation 0.29 which is somewhat lower than the corresponding values for the questions in Table 1 but is still acceptable.

Evaluation against the five principles of Cooperative learning

Positive interdependence was built into the procedure. Students worked in groups of two, received a single problem statement per group and handed in a single solution. They also received a challenging problem – typically from an exam paper of a previous year – of which the solution was not immediately apparent. It was therefore almost natural to turn to your partner and rely on him/her for help. From observation it was clear that the team members were generally committed to their groups. Most of the time they stayed together until the problem was solved.

Individual accountability. From the interviews it was clear that students did not always prepare well for the tutorials. The fact that they could choose their own partner made it easier to come unprepared. However, the aim of scheduling an individual test during the next PPS tutorial was to encourage students to participate and contribute while solving the tutorial problems in order to be better prepared for the upcoming test. From the high average achieved by Question 1 it seems the small tests were effective in encouraging students to take personal responsibility for their own learning. None of the interviewees mentioned partners that dodged their responsibility; so perhaps it can be assumed that generally both partners took responsibility and participated during the tutorial.

Promotive interaction. We found that almost without exception, receiving the problem statement precipitated activity and discussion. From the interviews it also seemed that team members helped each other. This is confirmed by the relatively high score achieved by Question 7.

Social skills. Because the tutorials did not count, the atmosphere was relaxed. Because guidance was readily available, any difference in opinion could easily be resolved by consulting the lecturer or another group. It seemed that the group members generally cooperated well. Isolated instances where team members worked parallel to each other did occur.

Group processing. During our first attempt (van Niekerk 2011) we tried to implement a formal “buddy-rating” system but because the students did not want to cause ill-will between themselves they consistently gave each other unrealistically high ratings. We therefore decided on a more informal approach and encouraged them to thank each other at the completion of the tutorial.

Implementation

Two aspects are important here: Overcoming student resistance and minimizing the additional effort needed to implement PPS.

Students are used to being passive and being allowed to work individually. Therefore some resistance can be expected. It is therefore necessary to motivate and explain the procedure properly and find the right balance between standing firm and adapting. As they experienced the advantage of working together, it became easier to obtain their cooperation – which was crucial with a class of 180. The random pairing was abandoned because of student resistance (which can also be seen in the response to question 12 of the questionnaire) and we allowed them to choose their own partners.

The weekly assessments required substantial additional effort. Setting up new problems for the pairs to work on, was extra effort but is not a necessary requirement for PPS to be effective.

Conclusions

A successful procedure was developed for implementing PPS in Thermodynamics. The students feel positive about PPS. It reduced their feeling of uncertainty when faced with a problem and exposed them to alternative problem-solving strategies – which improved their problem-solving skills. From interviews it is clear that they realise that developing their problem-solving skills is important in Thermodynamics.

Although we are convinced that PPS is a viable strategy, we still see this as “work in progress”. Positive interdependence can be easily built into the implementation structure. Promotive interaction almost seems to come naturally to the students. Because only two people are involved and the goal is simple – solve the problem! – interaction is less complicated. Formal group processing may make people feel awkward. Feedback can be implemented in a more spontaneous way by asking partners to thank each other or visibly show their joy at solving a problem.

The challenge lies in ensuring individual accountability. It is important to find an easy effective way of ensuring that students come prepared to PPS sessions, contribute during the session and take responsibility for his/her own learning. Individual tests after a PPS session encouraged students to take the PPS session seriously, but at this stage it is substantial additional effort and must be weighed against the gains. Making use of web-based evaluations can be considered to reduce the workload.

The strategy followed by many students, namely getting hold of as many worked out problems as possible and the recurring demand that the lecturer do more and more problems on the board still seems to be strong. It is possible that the adaptations made to the implementation procedure of PPS as we went along, substantially reduced the efficiency of PPS and that in a next round the demand for worked out problems will be lower.

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