Student Engagement in a Structured Problem-based Approach to Learning: a Heat Transfer Course in First Year Electronic Engineering

Eduardo Montero¹, María Jesús González¹, Fernando Lara², Fernando Aguilar¹, Cristina Alonso¹
¹Electromechanical Engineering Department, ²Education Sciences Department
Escuela Politécnica Superior, Universidad de Burgos, Spain
Avenida Cantabria, s/n, 09006 Burgos (Spain), emontero@ubu.es, mjgf@ubu.es, flara@ubu.es, faguilar@ubu.es, catristan@ubu.es

Abstract - Problem-based Learning has been at the core of significant developments in engineering education in recent years. It refers to any learning environment in which the problem drives the learning. The problem is posed so that the students realize that they need to acquire some new knowledge before they can solve the problem. This paper presents an experience of a structured problem-based approach to teaching an introductory course on Heat Transfer in the first year of an Electronic Engineering graduate programme. A heat sink design problem is posed to students at the beginning of the module. Small groups of students have worked together in cooperative learning for ten weeks, the teacher being the coach and facilitator of the knowledge acquisition. Partial, not extensive written reports have been collated weekly. Student's assessment of the learning environment has been measured. A list of recommendations is presented with a view to assist academics interested to adopt a similar approach.

Index Terms - problem-based learning, cooperative learning, engineering thermodynamics.

INTRODUCTION

Rapidly changing technology means that graduates of engineering programs need to acquire important qualities of lifelong learning and self learning skills to support a through-life ability to respond to advances in technology. Amongst other general skills, such as teamwork, creative thinking, communication or critical-self awareness, one of the most important skills that assist lifelong learning is the ability of the graduate for self driven learning. The industry [1] demands and expects from engineers a wide range of these generic skills in addition to a high degree of technical competence. Furthermore, many engineering institutions and associations [2]-[6] include this appreciation in their reports. The learning and development of these skills is only possible if, as much as the scientific knowledge, their achievement is a self-building process of the student. Ability and interest in self-directed learning, therefore, can be considered synonymous with lifelong learning. In turn, teachers must become guides in the learning process which is not limited only to the subject matter of their own course, but which must be infused with a good dose of these skills.

This paper presents the experience of teachers, student achievements and evaluations in a course of ‘Introduction to Heat Transfer’. The paper presents first the fundamentals of the learning strategy adopted, intended to develop lifelong learning abilities in the students. It then describes the context and challenges faced in the case study, the essentials of the learning activities proposed, as well as the student’s achievements and evaluation. Finally a list of recommendations, based on the experiences gained in this course, is presented.

LEARNING STRATEGIES IN ENGINEERING EDUCATION: THE PROBLEM-BASED LEARNING APPROACH

Research has shown that the approach that the students take to learn a particular task is an important factor in determining learning outcomes [7]. A surface approach focuses on discrete pieces of knowledge, without attempt to integrate them, learning just the unrelated facts. Students who see learning as increasing knowledge or memorization, that is, who see the process of learning as external to themselves, tend to use surface approaches and their focus is on satisfying assessment requirements. In contrast, in a deep approach to learning, the student looks for underlying meaning and structure, taking a holistic view. Such students see learning as an internal process, one that involves them acting upon the material in order to give it some meaning to themselves, learning the facts in relation to the concepts, accordingly to the socio-constructivist theory of learning. This theory argues that learning involves the construction of knowledge and that learners must actively seek to make meaning from their experiences by relating new information to what they already know. An important thing to note here is that the approach to learning is not a fixed characteristic of an individual [8], thus it is incorrect to speak of deep and surface learners. Rather, all learners are capable of using both deep and surface approaches, and it is their perception of the demands of a task that largely determines which approach they actually use.

Socio-constructivist theory suggest, therefore, that deep approaches to learning are more likely than surface approaches to lead to understanding and enduring learning.
Students who use a deep approach to learning gain higher grades, and are more likely to remember material and to be able to apply it to unfamiliar situations. In contrast, the use of a surface approach is associated with low quality and ineffective learning: short-term goals, such as passing exams, may be achieved, but much of what was ‘learned’ is quickly forgotten. Effective learning is more likely when students are given, and accept responsibility for their own learning and have some control over the learning context. Widespread use of formal lectures does not make this possible, but small group work, if structured to enable cooperative learning, can enable student autonomy. Such work is associated with the use of deep approaches and high quality learning outcomes. One example of this type of work is Problem-based Learning (PBL), where a group of students work collaboratively to solve a particular problem. There is enough evidence in the literature that PBL assists in developing problem solving and lifelong learning abilities, and has been at the core of significant developments in engineering education in recent years. Moreover, the similarity between PBL and engineering management in industry has been established. PBL is any learning environment in which the problem drives the learning. That is, before students learn some knowledge they are given a problem. The problem is posed so that the students discover that they need to learn some new knowledge before they can solve the problem. Learning in the context of the need-to-solve-a-problem tends to motivate students and also tends to store the knowledge in memory patterns that facilitate later recall for solving problems. PBL environments include research projects, as well as engineering design problems that are more than a synthesis of previously learned knowledge. Using this approach requires also that teachers change. This change, in particular, expects teacher to change their role from being the centre of attention and the source of all knowledge to being the coach and facilitator of the acquisition of that knowledge. The learning becomes student-centred instead of teacher-centred.

Some researchers emphasize that PBL should involve open ended problems right from the start, and this is the common rule for senior levels. That is, the problem is not clearly defined, as is the case of many real problems. Students must recognize the problem, identify and acquire the skills and knowledge needed to solve it, investigate possible alternative solutions and learn along the way. Students are required to take responsibility for their own and the group’s learning, and hence are both autonomous and independent. Learning is self-paced and takes place in the context of a realistic problem, the manner of working being close to that of engineers in industry. Engineers see themselves as problem-solvers, so the learning context is seen by students as being relevant. However, if the students have deficiencies in the required background technical knowledge or lack of the generic skills necessary to undertake self-directed study, then it is very likely that the goals of an open ended problem-based strategy will not be achieved, with the subsequent student’s frustration. In the case of junior levels course, due to the heterogeneity and diversity of the scientific and technical knowledge student’s background, a more structured approach is advisable. There is evidence that a problem-based approach that has a structured form initially, with clearly defined problems, and then gradually move toward open ended problems is useful for junior level courses. Another aspect of this learning context not to be forgotten is assessment. More than any other single factor, assessment defines the curriculum for a student, which is driven mainly by the external demands of the assessment system. Therefore, assessment needs to be seen as part of the teaching of the PBL approach.

**Case Study: Context and Challenges**

A structured PBL strategy has been used in the course entitled ‘Introduction to Heat Transfer’ during the academic course 2005/2006. This course is taught over a period of 6 weeks, for five hours of timetable contact a week (2 classroom/theory hours, 3 seminar/laboratory hours). This subject is included in the first year of the three-year undergraduate program leading to a degree in Electronic Engineering at the High Polytechnic School of the University of Burgos (Spain). It is a compulsory course with the objective of obtaining a fundamental knowledge of heat transfer mechanisms, with an especial focus on electronic devices. The program of contents is a reduced version of what can be founded in any heat transfer handbook, accordingly to the course duration. Further applications will be founded later in the course ‘Power Electronics’, in the third year of the same degree in Electronic Engineering.

For the last 6 years, a traditional approach based on lectures and some practical laboratory sessions was used. As this course is taught at the same time that the courses ‘Fundamentals of Mathematics’ and ‘Fundamentals of Physics’, in the same first year, some lacks of fundamental knowledge is always found in the students, and the development of the mathematical structure of heat transfer science is very limited due to the previous student’s background. Within this context, the lectures have been limited to the study of the most elemental cases on conduction heat transfer. This teacher-centred learning is only partially compensated by the laboratory sessions, where students were involved in a more active and cooperative approach, using an adapted ‘learning by investigation’ approach. Convection heat transfer phenomena were studied using an experimental bench, and the expected learning is developed through some design situations, team work and oral and written communication activities. The fundamentals and results of this learning experience are described in reference [21]. The assessment scheme adopted in the course was 70% for a final exam and 30% for the laboratory work, so the exam was the driven-force for the student’s learning, minimizing the impact of the more active task at the laboratory. A revision of the examination results along the years has shown that the surface approach to learning is adopted by the majority of students. Good marks in exams were correlated with questions and problems that were alike the ones taught in the lectures, while bad marks were obtained when data or questions of similar nature were asked.

---

**Session T1B**

A structured PBL strategy has been used in the course entitled ‘Introduction to Heat Transfer’ during the academic course 2005/2006. This course is taught over a period of 6 weeks, for five hours of timetable contact a week (2 classroom/theory hours, 3 seminar/laboratory hours). This subject is included in the first year of the three-year undergraduate program leading to a degree in Electronic Engineering at the High Polytechnic School of the University of Burgos (Spain). It is a compulsory course with the objective of obtaining a fundamental knowledge of heat transfer mechanisms, with an especial focus on electronic devices. The program of contents is a reduced version of what can be founded in any heat transfer handbook, accordingly to the course duration. Further applications will be founded later in the course ‘Power Electronics’, in the third year of the same degree in Electronic Engineering.

For the last 6 years, a traditional approach based on lectures and some practical laboratory sessions was used. As this course is taught at the same time that the courses ‘Fundamentals of Mathematics’ and ‘Fundamentals of Physics’, in the same first year, some lacks of fundamental knowledge is always found in the students, and the development of the mathematical structure of heat transfer science is very limited due to the previous student’s background. Within this context, the lectures have been limited to the study of the most elemental cases on conduction heat transfer. This teacher-centred learning is only partially compensated by the laboratory sessions, where students were involved in a more active and cooperative approach, using an adapted ‘learning by investigation’ approach. Convection heat transfer phenomena were studied using an experimental bench, and the expected learning is developed through some design situations, team work and oral and written communication activities. The fundamentals and results of this learning experience are described in reference [21]. The assessment scheme adopted in the course was 70% for a final exam and 30% for the laboratory work, so the exam was the driven-force for the student’s learning, minimizing the impact of the more active task at the laboratory. A revision of the examination results along the years has shown that the surface approach to learning is adopted by the majority of students. Good marks in exams were correlated with questions and problems that were alike the ones taught in the lectures, while bad marks were obtained when data or questions of similar nature were asked.
difficulty about the same subject were posed in a different manner. Pass the exam was the main goal achieved by the students.

During the academic year 2005/2006, a structured PBL approach has been used in the course. With a total number of forty-one students distributed in nine teams of four to five people, students would start working with very simple clearly defined problems and move gradually towards a more complex problem. The early problems would be aimed at enabling students to gain some fundamental knowledge about the heat transfer fundamentals as well as to give them some time to know each other in the teams. Due to the academic schemes and directives, there was no possibility of avoiding the traditional weekly timetable. So, the students have attended the formal lectures as an only group and have worked in teams during the seminar hours, divided in two groups of 4 and 5 teams each.

The problem posed was the design of a natural convection rectangular heat sink for refrigeration of an AC/DC converter using diodes. Electronic and thermal data of a different diode were supplied to each team. As the intended learning objectives were the conceptual learning of heat transfer mechanisms and the ability to conceive simple applications, no electronic/thermal design software was supplied. Instead, at least 20 to 25 different heat transfer textbooks and handbooks, from the Department Library or from the University General Library, were available during the seminar’s work.

Conditioned to attend formal lectures in the classroom, the first early problem posed to the students was the need to program the scientific contents of these lectures. The only guide given was that they should be useful for understanding the conceptual basis of the design problem in charge, and should be prepared and taught by the teacher. Each team, with the help of textbooks and handbooks, proposed its own program of contents for each one of the lectures. The final program was obtained after discussion and agreement of the proposals. So, the students took responsibility for their own and the group’s learning.

The rest of the early problems were posed in the seminar timetable along the weeks two to four, in the form of small problems of simple conduction and convection heat transfer applications of increasing complexity. The objective was to reinforce the student’s understanding of the thermal resistance concept and the design skills of heat transfer devices. The last two weeks were devoted to the final capstone design problem of the natural convection heat sink. Apart the contact hours, the teacher has estimated a need of personal homework of about 20 hours/person to complete the required task. This estimation has been advised to the students from the beginning.

The assessment scheme adopted was of continuous and progressive evaluation. Each team of students had to present a report of the corresponding problem each week, and the final problem could be presented one week after the end of the module. In addition, a short individual exam was introduced in week 5 to differentiate individuals among the teams. Table 1 shows a summary of the organizational scheme.

<table>
<thead>
<tr>
<th>Week No.</th>
<th>Lecture</th>
<th>Work in Teams</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction</td>
<td>Program of contents</td>
<td>Report 0%</td>
</tr>
<tr>
<td>2</td>
<td>Lecture 1</td>
<td>Problem 1</td>
<td>Report 5%</td>
</tr>
<tr>
<td>3</td>
<td>Lecture 2</td>
<td>Problem 1</td>
<td>Report 5%</td>
</tr>
<tr>
<td>4</td>
<td>Lecture 3</td>
<td>Problem 1</td>
<td>Report 15%</td>
</tr>
<tr>
<td>5</td>
<td>Lecture 4</td>
<td>Final problem</td>
<td>Individual exam 25%</td>
</tr>
<tr>
<td>6</td>
<td>Lecture 5</td>
<td>Final problem</td>
<td>(1 week delay) 50%</td>
</tr>
</tbody>
</table>

The progressive evaluation means that the later projects have had more weight that the earlier ones, being the final problem the 50% of the total weight. It has been supposed that learning of knowledge and development of general skills are cumulative, so the assessment criteria increase as it does the complexity and relevance of problems.

**RESULTS AND DISCUSSION**

Forty-one students involved in the PBL instructional approach were surveyed in the first semester of 2006. Several tools have been used to evaluate the impact of PBL on student’s learning. First of all, an evaluation of the scientific designs and reports presented by the students was carried out. Second, observations of the behaviour of students were made during the teaching sessions. And third, student attitudes and perceptions to this sort of learning strategy were gauged through an anonymous questionnaire.

The final grades obtained by the students were quite good. A 27% of them obtained Very Good Marks and 51% Good Marks, while 22% obtained Bad Marks. These academic results are very likely the results obtained with the previous traditional approach. However, in the traditional approach, the level of difficulty of the exam was similar to the individual exam passed by the case study students in week five. As it has been said, good marks obtained in the traditional exam approach are heavily correlated to surface learning, while in this case, all the students that obtained good mark in the individual exam have also obtained a good mark in the final design problem, which means that the knowledge acquired was deep, well integrated.

An additional comment of interest is the difference found between the two seminar groups. As well as lecture groups can include a great number of students, seminar or laboratory groups are constituted of a maximum of twenty-four students. In our case, the forty-one students of this course are divided in two smaller seminar groups: group A, with 19 students, and group B, with 22 students. Being made this division by application of faculty management criteria, the global marks for group A (58% Very Good Marks and 42% Good Marks, 0% Bad Marks) are enough better than for group B. A similar
difference is observed also in partial evaluation of early and final problems, as is shown in table 2.

<table>
<thead>
<tr>
<th>Problem No.</th>
<th>Group A mean value</th>
<th>Group B mean value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem 1</td>
<td>4.2</td>
<td>7.0</td>
</tr>
<tr>
<td>Problem 1</td>
<td>6.6</td>
<td>5.1</td>
</tr>
<tr>
<td>Problem 1</td>
<td>10.0</td>
<td>7.9</td>
</tr>
<tr>
<td>Problem 1</td>
<td>5.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Final problem</td>
<td>7.5</td>
<td>4.6</td>
</tr>
<tr>
<td>Global Mark</td>
<td>7.1</td>
<td>4.7</td>
</tr>
</tbody>
</table>

Over the six seminar sessions of three hours each with each group, the teacher has had great opportunity of observe the attitudes and behaviour of students. Some of the most relevant are the following:

- In some teams, a leader has appeared early and the team work has been efficient from the beginning, tough some members seemed to be more passive. In other teams, a most cooperative and balanced work has been developed amongst its members. In both cases, the student’s achievements and marks have been quite good. In the opposite, groups that have obtained poor marks appeared to be confused about the task proposed, each member working on its own, with difficulties to organize their time adequately during the work sessions,
- In relation with the traditional approach, the number of questions posed to the teacher during the sessions is considerably higher. It has been time enough for the teacher to have personal interaction with each team and to attend demands and questions about the task in charge.
- The student’s background of mathematical knowledge is quite poor. Therefore, complimentary explanations from the teacher have been necessary. This barrier has implied an additional effort for the students.
- The use of textbooks and handbooks has greatly broadened respect the traditional approach, more based on notes taken during the lectures. A majority of students have shown great ability to find, select and use the most adequate books for the required purpose. As first year students, they have had the opportunity to discover the great potential of the Library. Some students were not able to use English language books.

Student attitudes and perceptions to this learning approach were surveyed through an anonymous questionnaire of 10 items, shown in Table 3. Information was gathered by the explanation of the PBL was presented to students (pre-test), the second the last day of class but before the final project was evaluated (post-test). Although forty-two students were involved in the subject, only thirty students completed both questionnaires (15 from group A and 15 from group B). Results in Tables 4 are referred to them.

Table 4 presents the results of the post-test. Mean values of all items are comprised between 3.21 and 4.20. In all questions, the modal response is placed over the ‘agree’ response, except in questions 2 and 4 that is ‘neutral’.

<table>
<thead>
<tr>
<th>Question No.</th>
<th>Statement</th>
<th>1 Strongly disagree</th>
<th>2 Disagree</th>
<th>3 Neutral</th>
<th>4 Agree</th>
<th>5 Strongly agree</th>
<th>Mean Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>I have taken many notes during the seminar sessions</td>
<td>0</td>
<td>3</td>
<td>33</td>
<td>57</td>
<td>7</td>
<td>3.67</td>
</tr>
<tr>
<td>Q2</td>
<td>The open and design situations presented are interesting</td>
<td>3</td>
<td>7</td>
<td>60</td>
<td>27</td>
<td>3</td>
<td>3.21</td>
</tr>
<tr>
<td>Q3</td>
<td>There is great opportunity to participate and ask questions during the sessions</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>60</td>
<td>10</td>
<td>3.69</td>
</tr>
<tr>
<td>Q4</td>
<td>It is easy to me to ask questions during the sessions</td>
<td>3</td>
<td>13</td>
<td>44</td>
<td>33</td>
<td>7</td>
<td>3.27</td>
</tr>
<tr>
<td>Q5</td>
<td>I have been able to propose hypotheses based in my prior knowledge</td>
<td>7</td>
<td>3</td>
<td>43</td>
<td>47</td>
<td>0</td>
<td>3.30</td>
</tr>
<tr>
<td>Q6</td>
<td>Having the opportunity of proposing my own ideas to design devices has been very useful</td>
<td>3</td>
<td>17</td>
<td>37</td>
<td>40</td>
<td>3</td>
<td>3.23</td>
</tr>
<tr>
<td>Q7</td>
<td>The obligatory reports we have had do waste have improved my learning</td>
<td>0</td>
<td>23</td>
<td>20</td>
<td>43</td>
<td>14</td>
<td>3.47</td>
</tr>
<tr>
<td>Q8</td>
<td>The teamwork is better way to learn than on my own</td>
<td>0</td>
<td>10</td>
<td>3</td>
<td>44</td>
<td>43</td>
<td>4.20</td>
</tr>
<tr>
<td>Q9</td>
<td>I have learned more with the group discussion than if it shouldn’t have take place</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>37</td>
<td>33</td>
<td>3.93</td>
</tr>
<tr>
<td>Q10</td>
<td>I have listened carefully the statements and proposals of the others during the group discussion</td>
<td>0</td>
<td>3</td>
<td>27</td>
<td>53</td>
<td>17</td>
<td>3.83</td>
</tr>
</tbody>
</table>

In relation with the results shown in Table 4, we can appreciate that students generally felt that the learning experience was relevant. Teamwork is recognised as the most valuable characteristic of the sessions (Q8, m.v. 4.20, 87% of global agreement) and the students feel that improve their learning. Although the critical attitude of students towards others classmates in the groups is variable, teamwork has been recognised to improve relational skills as a great value of the sessions (Q9, m.v. 3.93; Q10, m.v. 3.83), with modal responses of global agreement of 70%.

Even though the opportunity to participate and pose questions has been found to be of great interest (Q3, m.v. 3.69), the students are not used to take advantage of it (Q4, m.v. 3.27). The proposal of design tasks has been demonstrated of moderate interest for student’s learning (Q2, m.v. 3.21; Q5, m.v. 3.30; Q6, m.v. 3.23), probably due to the considerable mathematical effort required.
The student’s perception of effective learning is due also to the effort needed to write reports (Q7, m.v. 3.47). For this purpose, active attitude during teacher explanations or group discussion has received a good score (Q1, m.v. 3.67).

Comparison between student’s responses to post-test from group A respect group B shows a slight higher mean values in the former, which implies that, as mentioned above, students from group A, that take a deep approach to learning, find PBL more interesting.

Mean values of the post-test are lower than the ones in the pre-test in all questions, except in the teamwork valuation  and more interesting.

from group A, that take a deep approach to learning, find PB L group A respect group B shows a slight higher mean values in

Discussion has received a good score (Q1, m.v. 3.67).

The questionnaire included a last question about if ‘Globally, the project has been of interest’. The score obtained is quite good, with a mean value of 3.77. Again the mean value of group A (3.93) is higher than group B (3.63), reinforcing the conclusion that the intrinsic motivation of students plays a central role in engineering learning.

CONCLUSIONS

The training of engineers has been undergoing a great deal of change for several decades. The preponderance of scientific contents and techniques in this training has given way to the inclusion of formative objectives in personal attitudes and skills that will be very important later in the engineer's professional career.

A structured Problem-based learning approach in an introductory Heat Transfer course has been presented. The experience gained from this course revealed that several issues are important for effectiveness of a structured PBL approach in first year engineering courses.

This approach allows the students the achievement of activities directly related to engineer’s professional work: design of equipment for an established purpose, literature research, communication and discussion of results and write up of reports.

It is important to start with simple problems covering some basic, background knowledge in the field. This would give all students opportunities to refresh the prerequisite knowledge.

Special attention must be paid to lacks of background knowledge and skills necessary to out complex problems. Complementary efforts should be made to address any deficiency students may have in the required background knowledge.

It is useful to increase the complexities of the problems gradually so that there is not a huge gap in the level of knowledge and design skills encompassed by consecutive problems.

It is important to have one capstone problem/project at the end which would challenge the students. Such problems would deliver best learning and skill development if they are open-ended and require self-directed study, literature review and problem solving.

There must be a relevant percentage assessment weighting in the open-ended problem in order to motivate and engage students. However, it could be considered the possibility of some formal, individual examination in order to test the knowledge of the students on a broader range of topics covered in the course.

ACKNOWLEDGEMENT

The research team wish to thank the Agencia para la Calidad del Sistema Universitario de Castilla y León (Spain) ACSCUCYL (Innovation Experiences Programme oriented to the Higher Education European Area, Project UB 12/04) for supporting this work.

REFERENCES


