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Development of Transferable Skills within an Engineering Science Context using Problem-Based Learning*

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This paper discusses teamwork skills and independent-learning skills that enhance active learning. Problem-based learning (PBL) was incorporated into science, where real-life problems were chosen from the field of engineering to motivate students to activate and develop these skills. The analysis of students' questionnaires shows that engineering students have positive attitudes toward cooperative learning and towards the use of computers in engineering problem solving. Students, who were taught using PBL rated their progress in teamwork skills significantly higher than their peers who were taught in the traditional way. Moreover, the PBL participants reported significant improvement in independent-learning skills using a computer.

Keywords: Engineering education; learning; teaching methods; teamwork; computer-aided instruction

INTRODUCTION

UNDERGRADUATE ENGINEERING EDUCATION needs to consider the demands set by industry. Corporations and employers have frequently and publicly complained about the lack of professional awareness and the low levels of communication and teamwork skills of engineering graduates. They urge universities to produce graduates with the knowledge and skills necessary to ensure their swift transition from new recruits to productive employees [1]. Moreover, engineers need to absorb vast amounts of scientific knowledge, which is increasing more rapidly than engineering curricula can follow. Students need to adapt to the rapidly changing technology and be prepared for quick changes and unusual situations in the engineering profession [2]. To overcome the notorious lack of time in the curriculum schedule in present-day education, engineering students need to learn efficiently to get applicable knowledge, and acquire problem-solving and independent-learning skills support for lifelong learning using computers. For undergraduate education it is important to increase student participation in an active learning process and to provide a skill-based education as well as one based on academic achievements [3]. For this reason teaching strategies for engineers should follow more student-based instructional approaches. Problem-based learning (PBL) is such an approach, where applicable knowledge and transferable skills can be successfully developed [4]. Activity-based learning is a central part of the PBL learning process, requiring activities involving research, decision-making and writing [5].

This paper focuses on the development of teamwork skills and independent-learning skills in an undergraduate time-pressured engineering course. PBL is used in statistics with probability (which is part of engineering mathematics), which provides sufficient applicable knowledge and skills needed in other engineering disciplines and in practice. At the end of the course students' attitudes on the importance of such skills and students' development of these skills in practical situations was analyzed.

PBL IN THE ENGINEERING CURRICULUM

Boud and Feletti [6] define PBL as a carefully planned curriculum, which is entirely based on solving practical problems. Problems trigger learning of the given content and constitute the motivation for the students' activities [7]. Students are actively involved in the learning process. They solve problems in small groups, where cooperative learning is encouraged. At the beginning of the problem-solving process the students should draw on their prior knowledge, whereby possible ways of problem solving and the gaps in knowledge are determined. After identifying the gaps in their knowledge, they define the learning objectives needed for solving the problem. Students search for additional information individually and synthesize all the knowledge to solve the problem in groups. The teacher is a facilitator, who assists

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the students in the learning process and develops the students' independent-learning capacities [8]. Classical lecturing can play only a supportive role in the process.

In PBL the acquired knowledge, transferable skills and the student's ability to solve real-life problems are assessed, rather than the student's test writing skills. A very important function of assessment is to give the student immediate feedback on whether his / her learning process is adequate, whether the expected development of skills is achieved and whether a certain knowledge or skill needs to be improved. It is in fact the assessment system that dictates learning and the work carried out by students [9].

Many authors have reported that PBL is successful in engineering education [10, 11]. Steinmann [12] used PBL in a new course in engineering curriculum for sustainable development in undergraduate education. In our case we implemented this teaching approach into an existing engineering statistics course [13] similarly to that reported by Bowe and others [14] or Senocak and others [15]. No additional time was needed in the schedule for developing transferable skills through PBL. Of course, a certain number of hours of the science course needed to be devoted to skills development and organization on account of specific science contents [16].

Teamwork skills in PBL for engineers

Engineers need to work cooperatively. They need to know how to communicate with other engineers and specialists, to share obligations in projects to achieve the goals. PBL gives students opportunities to learn in small groups and gain practical experience while working in a team. Some of the benefits are listed below.

1. Collaboration in PBL is a way to establish a connection with prior information and to confront students with the beliefs of others [17]. Students can get a real picture of the knowledge that they have acquired in the past by listening to others' experiences or information. In this way they can acquire the more complex knowledge needed for problem solving, which is underpinned by the theory of constructivism. In fact, PBL derives from the premises of constructivism [18].
2. At the initial stage of PBL students should draw on their prior knowledge, and the gaps in their knowledge can then be defined. In teamwork students can recognize any misconceptions which may provide poor foundations for the integration of new knowledge into their own cognitive structures. Therefore, guided cooperative learning in small groups with facilitators will lead to productive discussion and the acquisition of new knowledge [10]. This is unlike a lecture-based teaching approach where misunderstandings may not be discovered until the exam.
3. Working in groups through PBL gives members of the group an opportunity to develop problem-solving skills, teamwork skills, independent-learning skills and self-assessment skills; these are important in engineering, because most engineering is done cooperatively.
4. As a student works in a group, their questions can stimulate them, or their group members to hypothesize, predict, puzzle, explain and reflect on their ideas [19]. Each individual contribution is important for group success, so this is good practice for raising a sense of responsibility and discipline.

However, teamwork in PBL can also have some negative effects:

1. Sometimes learning in teams requires more time because extra time is needed for concept negotiation, explanation, reconciliation, procedural discussion and administration [20].
2. Teamwork learning of some science contents does not serve for proper structuring of new knowledge: some topics can be overlooked because students make their own learning objectives [10]. Therefore, carefully chosen problems and facilitator's feedback and additional questions in problem solving can lead students in structuring appropriate knowledge [21].
3. Teamwork in PBL needs a lot of energy, because members need to focus their energy on cooperation, explanation, organization of teamwork, writing notes, minutes, etc. If groups are not appropriately formed (this happens more often in some heterogeneous groups), work can sometimes even lead to frustration [19].
4. Assessment in PBL can be difficult, since the contribution of an individual to a group needs to be evaluated. Alternative assessment methods need to be introduced, e.g. peer-assessment and self-assessment [22].

Independent-learning skills in PBL for engineers

In this modern era, characterized by a rapid expansion of knowledge, young people need to learn how to search effectively for relevant information, how to select it critically and adopt the most efficient learning strategies. These capabilities are captured in independent-learning skills, defined as skills in PBL that are necessary to carry out individual activities [23, p. 13]. Students will also need these skills later for lifelong learning in the engineering profession.

In the field of engineering in particular, modern technology is very important for the development of independent-learning skills such as: independent searching for relevant information, independent processing of information, cognitive integration of new and old information, and mediation of new information to others. Computers play a crucial role in this respect [24]. In PBL, independent-learning skills are crucial once the students have set their learning objectives and when they need to find new information for solving a problem.

IMPLEMENTATION OF PBL IN THE COURSE OF BASIC ENGINEERING STATISTICS

For the purposes of implementing PBL in teaching basic engineering statistics a PBL model was designed [13]. This model integrates statistics, engineering fields and ICT. The course consists of several "problem" phases. During each phase there are 2–4 meetings of PBL groups (consisting of five members), and the whole problem-solving cycle takes from one week to one month. In each phase interdisciplinary problems drive students' cooperative learning. The difficulty of the problems and the time needed for problem solving process increase with each subsequent phase. The facilitator manages approx. 6–8 groups simultaneously and plays the role of a tutor and facilitator. For some time at least the facilitator needs to become a member of the group and cooperate with the students, giving them feedback after each problem solving cycle. The roles of group members rotate: a chairperson ensures that all the students are active and a secretary sums up discussions and writes down the minutes. At the end of the course students complete an extensive problem that resembles an engineering project. They need to report, present and defend the project in the same way as those in the engineering profession.

With different problems, approximately three quarters of the statistical syllabus is covered. As for the rest of the syllabus, students must listen to the presentations of other groups. In this way, they get a glimpse of the remaining part of the syllabus. Mastering transferable skills helps them later, when they come across a similar problem. In this way the first mentioned negative effect of teamwork can be reduced. Lectures that follow the PBL process (and not the other way round) help students to structure the learning content and reduce the negative effect mentioned under item 2. Students are free to choose their own groups according to their field of interests and their preferences, which reduces the negative effect under item 3. To avoid problems of assessment, students assess themselves (self-assessment), and other group members (peer-assessment), in this way helping the facilitator to arrive at the final mark for each group member [13]. The facilitator checks problems after each phase, and gives students feedback about any deficiency in their knowledge or skills. At the end of the PBL course, the facilitator verifies the students' progress again in a portfolio and assesses the students' public presentations and defense of the project.

Students can use computers during the engineering statistics course, practice independent-learning skills with computer support and become aware of the importance of this tool. Problems are designed in such a way that for each problem more independent-learning skills with computer support are introduced. In this way, students solve statistical problems, and apply different strategies, step by step and improve web data searches, use electronic data processing programs with data display methods (tables, graphs, functions, diagrams, etc.), learn basic (statistical) data calculation (i.e. calculation of functions with given data, exclusion and selection of data with specific characteristics, data calculation of basic statistical characteristics of a population or a sample, etc.) and advanced statistical calculation (testing hypotheses, regression, etc.).

ANALYSIS OF TRANSFERABLE SKILLS IN PBL

In order to find whether PBL leads to better knowledge and skills and whether the students liked the new way of learning, all engineering students from the Department of Technical Safety at the University of Ljubljana were randomly put into one of two groups: Experimental group (EXP; $n = 38$) with PBL and Control group (CON; $n = 38$) with traditional instruction.

Both types of instruction were organized in two-hour weekly sessions over one semester. The problems were presented to the EXP at the beginning of the "problem" phase. The students learned about a topic by solving a problem in small groups with computer support. However, the students in the CON were first introduced to the content through lectures by the instructor, and only then solved problems individually at the end of each phase.

At the end of the semester, the students' development and attitudes towards transferable skills (the most important for active learning) were measured together with the students' basic knowledge and problem-solving skills in real world situations (which are not the focus of this article). Before we present the results, it should be noted that measuring transferable skills is problematic. One reason is that teamwork—such as communication skills—can also be developed outside PBL. Another reason is that the students themselves can evaluate their own progress of transferable skills better than the teacher, if the teacher does not know to what extent these skills had been previously been developed. There is also a problem of self-confidence. Some students may already have developed these skills but were unable to demonstrate them.

We measured transferable skills in different ways. Indirectly, we compared the results of projects in the EXP and the CON. Students from the EXP (who solved problems cooperatively in teams) proved to be better than the students in the CON [16]. We measured the following directly. We used the Questionnaire about transferable skills to analyze students' attitudes toward teamwork and independent learning with the use of computer. A Questionnaire about instruction tested whether EXP students had in fact practiced teamwork skills more often than the CON students who learned in the traditional way. We analyzed the students' progress of their independent-learning skills in the Self-assessment Questionnaire.

Students' attitudes towards transferable skills in PBL

PBL students were asked to complete a Questionnaire about transferable skills. The Questionnaire included one section about teamwork and two sections about independent learning with computer support. Sections of the Questionnaire were organized as pairs of opposite adjectives. Students indicated their attitude by marking a cross against the corresponding adjective on a 7-grade scale. The two adjectives in a pair were always antonyms. The adjective, which was considered to translate a positive characteristic of an activity (e.g. cooperative learning in small groups in section 1), was called the "positive" adjective. The attitude expressed by the student was scored from –3 to 3 (3 for a "positive" statement).

The questionnaire had previously been tested on part-time engineering students. Based on the results obtained the pairs of opposite adjectives with the lowest discrimination performance were eliminated or reframed. The internal consistency for the grades referring to the adjectives in the first three sections of the questionnaire was found to be satisfactory (Cronbach coefficient alpha: $\alpha = 0.86$). All 25 students who attended and completed the PBL course filled in the questionnaire.

Section 1 consisted of 11 opposing pairs of adjectives. The averages of all the students' scores for all pairs of adjectives tended towards the "positive" side of the adjectives. Only the pair "demanding—easy" showed a negative mean value, tending slightly towards the adjective demanding, which was defined as "negative." We wanted to know whether the PBL students demonstrated a statistically significant tendency towards the "positive" adjectives across the different items. We posed the null hypothesis that the arithmetic mean value of the expressed attitudes was 0. Table 1 shows that 9 out of 11 null hypotheses were rejected by a two-sided t-test and by a Wilcoxon's signed-rank test, while 2 of the null hypotheses could not be rejected. We drew the conclusion that the students considered teamwork as useful, adequate, interesting, efficient, pleasant, dynamic, a good experience, organized, and simple. On the basis of the results it cannot be concluded, whether the PBL students found teamwork fast or slow. It is also impossible to say whether the students found it demanding or easy.

In section 2 a similar approach was taken to analyze the students' attitudes towards independent searching for specific information. Eight pairs of opposite adjectives were offered. On average all the scores tended toward the "positive" adjective side of the scale. According to the results of statistical analysis in Table 2 we rejected 7 hypotheses. The students who were offered PBL considered that the data search on the web was useful, successful, instructive, interesting, quick, clear and

Table 1. Results of the t-test (of the Wilcoxon's signed-rank test [25, p. 226]) on students' attitudes towards cooperative learning in small group

+ adjectives	*Mean*	*SD*	*df (N)*	*Statistic t(T)*
Useful	1.80	1.29	24(24)	6.971(14)**
Adequate	1.75	1.07	23(20)	7.987(0)**
Interesting	1.64	1.04	24(21)	7.915(0)**
Efficient	1.58	1.18	23(21)	6.593(5)**
Pleasant	1.58	1.25	23(18)	6.214(2)**
Dynamic	1.44	1.39	24(21)	5.192(12)**
Good experience	1.32	1.73	24(23)	3.825(42)**
Organised	1.24	1.27	24(22)	4.891(22)**
Simple	0.72	1.40	24(20)	2.571(42)*
Fast	0.04	1.67	24(19)	0.120(92)
Easy	–0.04	1.46	24(17)	–0.1373(79)

*** $p < 0.01$; * $p < 0.05$ in both tests*

Table 2. Results of the t-test (and of the Wilcoxon's signed-rank test [25, p. 226]) on students' attitudes toward independent search for specific information

+ adjectives	*Mean*	*SD*	*df (N)*	*Statistic t(T)*
Useful	2.00	0.82	24(24)	12.247(0)**
Successful	1.88	0.88	24(23)	10.666(0)**
Instructive	1.76	1.16	24(20)	7.555(0)**
Interesting	1.44	1.56	24(22)	4.625(25)**
Quick	1.32	1.68	24(21)	3.937(30)**
Clear	1.04	1.77	24(20)	2.942(37)**
Simple	0.67	1.40	23(19)	2.326(42)*
Easy	0.16	1.65	24(20)	0.485(93)

*** $p < 0.01$; * $p < 0.05$ in both tests* simple. On the basis of the results it is not possible to conclude whether the PBL students found the data search demanding or easy.

The attitude tested in section 3 was related to the independent processing and mediation of information with computer support as opposed to manual calculation. The mean values for all 10 pairs were on the side of the "positive" adjectives. Table 3 shows the results of statistical analysis. The students believed that independent processing and mediation of information with computer support in basic statistics course is accurate, useful, successful, efficient, clear, quick, and assures good quality, when compared with manual process and mediation. It was not possible to conclude whether the students found processing and mediation of information with computer support boring or interesting, demanding or easy, simple or complicated, when compared with manual calculation.

At the end of the Questionnaire about transferable skills the engineering students were asked whether they would prefer PBL with teamwork to the traditional method of instruction in their future statistic courses. Only 2 out of 25 students were more inclined to choose the traditional method of instruction; one student did not answer the question, while 22 students claimed that they would prefer to learn statistics cooperatively in small group.

Students' development of transferable skills

We used the Questionnaire about instruction to determine the students' progress in teamwork skills in the PBL environment. The questionnaire consisted of a 7-grade scale statements referred to active methods, motivation, difficulty and quality of instruction. Students had to evaluate their active participation in the learning process and development of their teamwork skills through the following statements (referred to active methods):

- I could improve my communication, presentation and administrative skills.—I could not improve my communication, presentation and administrative skills.
- I was involved in collaborative work.—The teacher guided the instruction.
- I actively participated in the instruction.—I was only a passive observer of the instruction.
- I prefer solving engineering problems with my peers.—I prefer solving engineering problems on my own.
- I could use computer during the teamwork.—Computers were not available during the teamwork.

On average, students of both groups were more inclined to choose the "positive" statements mentioned above (EXP: mean (SD) = 7.69 (4.65); CON: mean (SD) = 4.74 (4.23)). The scores of students in both groups were compared to find out whether the chosen methods of instruction (i.e. the PBL and the traditional instruction respectively) influenced the development of teamwork skills. The results obtained with two-sided t-test indicated that students in the EXP practiced teamwork skills more often than their peers in the CON ($t(41) = 2.219$, $p = 0.032$). The differences in motivation, difficulty and quality of instruction were not statistically significant.

The Self-assessment questionnaire was used to determine the students' progress in independent-learning skills in PBL environment. The question-

Table 3. Results of the t-test (and of Wilcoxon's signed-rank test [25, p. 226]) on students' attitudes toward independent process and mediation of information with computer support

+ adjectives	*Mean*	*SD*	*df (N)*	*Statistic t(T)*
Accurate	2.48	0.82	24(24)	15.074(0)**
Useful	2.04	1.17	24(25)	8.704(11)**
Successful	2.00	1.12	24(24)	8.944(4)**
Efficient	2.00	1.35	24(24)	7.385(19)**
Assures quality	2.00	1.12	24(25)	8.944(11)**
Clear	1.84	1.52	24(25)	6.058(30)**
Quick	1.28	1.90	24(21)	3.361(30)**
Interesting	0.68	1.89	24(20)	1.802(65)
Simple	0.64	1.82	24(16)	1.755(39)
Easy	0.56	1.61	24(18)	1.740(48)

** $p < 0.01$; * $p < 0.05$ in both tests

Table 4. Results of the t-test (and of Wilcoxon's signed-rank test [25, p. 226]) for matched pairs in the self-assessment scores across different activities

Activities	*Mean*	*SD*	*df (m)*	*t(T)*
Planning and organisation of learning	0.76	0.80	24(33)	4.645(41)**
Search for specific information	1.04	0.75	24(51)	6.958(49.5)**
Information transformation	0.76	0.58	24(46)	6.535(58)**
Information mediation	0.88	0.59	24(70)	7.498(85)**

** $p < 0.01$ in both tests.

naire had been tested before the main research and it was later changed considerably, because of a rather low correlation ratio of the total score $\eta_{yx} = 0.46$ [25, p. 280].

All students (n = 25), with the exception of two, completed questionnaire at the beginning and at the end of the course separately. The most substantial progress was made if a student assessed his / her initial performance with 1, and final performance with 5. In this case the student's progress was scored 4. The lowest level of progress was scored –4. We checked whether the score differences in self-assessment questionnaires were positive and analyzed the students' progress by computing the end-of-semester and the beginning-of-semester differences for the following features:

- Planning and organization of learning;
- Search for specific information;
- Information transformation;
- Information mediation.

Only 10 out of 300 scores were marked with negative values. The results in Table 4 show that the difference in the self-assessment score was statistically significantly higher than 0 for every observed skill in both types of analysis.

CONCLUSION

PBL is a good way of active learning to implement applicable knowledge and transferable skills from undergraduate education to practice. Boser [26] argues that the optimal way for developing problem-solving by engineers is a "small group problem-solving experience." Students who have experienced cooperative learning with PBL tend to have more highly developed critical thinking and problem solving skills, a lower level of anxiety and better and longer information retention [27]. The evaluation of Pearson [24] for example revealed that PBL provided a practical approach to investigating ICT, leading to new knowledge about challenges associated with the adoption and use of new technologies in various educational settings.

Incorporating PBL into a science course, such as basic engineering statistics, increases student motivation for learning the scientific content because they can also see benefits in engineering applications. An improvement of transferable skills, such as teamwork and independent-learning, using computer support in such a context can hopefully discharge time pressure in other engineering courses of undergraduate education. Nevertheless, a great deal of attention should be paid to the careful selection and design of problems from engineering fields, time distribution, facilitators' work and support, feedback and assessment, as well as to group formation and function, if we want to engage students effectively into active learning. All these factors are important for PBL environment where students will develop transferable skills not just practice them.

Analysis of the Questionnaires about transferable skills indicates that engineering students like cooperative learning in small groups and they mostly prefer this way of learning to traditional lectures in basic statistics course. They feel that independent web searching for specific information is a very useful learning process and has many positive characteristics. Students also prefer using computers for independent processing and mediating of information to manual processing.

In the Questionnaire about instruction, students with PBL assessed practicing and active participation in cooperative learning higher than the students learning engineering statistics traditionally. In the Self-assessment questionnaire students with PBL expressed significant progress in independent-learning skills using a computer.

We need to note that the sample of students in both groups who attended the course and answered the questionnaire was rather limited. It would be interesting to check how students in the CON (learning the traditional way without using computers during the instruction) would assess their improvement of independent-learning skills. Since only students with PBL were exposed to the use of computers and self-assessment, students learning the traditional way could not complete the self-assessment questionnaire. Nevertheless, the results of attitudes and the development of transferable skills are encouraging for other teachers who are planning to use PBL in their courses.

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