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Assessment in Problem-based Learning Incorporated into Traditional Engineering Education: Difficulties and Evaluation*

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Assessment in problem-based learning (PBL) incorporated into traditional engineering education should lead students to fulfil the PBL aims. Using process and outcome-oriented assessment methods, we introduced an assessment scheme that addresses all eleven outcomes of EAC 3 in engineering and contains individual and group assessment. The present article aims to expose and present difficulties of group assessment with 'problem projects' integrated in the assessment scheme. 'Problem projects' could provide an objective picture of individual student's knowledge, skills and progress if they are used in combination with other assessment elements from the scheme. The assessment scheme was used in an experiment, where PBL and traditional instruction were compared in an introductory statistics course. In the experiment, significant difference in students' achievements across 'problem projects' was observed. Despite difficulties in assessment the results encouraged us to use PBL also in other subjects.

Keywords: engineering education; problem-based learning; assessment; evaluation of teaching method

1. PROBLEM-BASED LEARNING IN ENGINEERING

MANY AUTHORS have reported that problem-based learning (PBL) is successful in engineering education [1–5], but only a few scientific articles have been published, where the authors were dealing with the comparison between the experimental effects of PBL and the traditional instruction [6, 3, 7]. Considering experimental data of PBL in medicine, Gijbels et al. [8] argued that an inappropriate and inhomogeneous assessment system can spoil the picture of success in PBL. This can hold true to an even greater extent, when talking about PBL in the studies of engineering than in medicine, since variability in the extent and contents is even greater in the field of engineering. In some cases, the whole engineering program can be converted to PBL [1]; PBL can be used in distance education in some parts of engineering [9], or applied in a particular study year [10]. In many other cases, PBL is adopted in one of the engineering courses [11–15]. Assessment systems are adapted to the differences in extent and content. Because of the different modalities of the PBL adoption, the assessment systems can vary considerably [7, 10, 11, 16]. This can be the reason for difficulties in the overall evaluation of PBL in engineering.

In PBL settings, it is difficult to objectively assess the skills of linking concepts and principles to procedures for implications and development of skills for successful problem solving in teamwork. Since engineers need to have a good basis of structured scientific knowledge, and transferable skills for successful problem solving to deal with engineering problems, assessment of all these components is needed. Teamwork is also obvious for engineers; therefore this learning setting is suitable. If some of the components are not assessed the students will not learn them [16]. There is also evidence of difficulty in assessing individual contribution in group work with peer- and self-assessment [10].

In this article we first introduce an assessment scheme of a PBL model for introductory engineering statistics. Then, we focus on students' assessment in 'problem projects' and describe the difficulties we experienced. Using a similar assessment scheme we finally introduce evaluation of students in the experiment. We analyse differences in students' achievements across different 'problem projects'. Furthermore, we evaluate the PBL model in comparison with the traditional instruction.

2. ASSESSMENT IN PBL

In comparison with traditional instruction, PBL requires different assessment methods [17]. As an approach in engineering it must demonstrate that the students have attained (EAC 2007-08 Criterion 3) [18]:

(a) An ability to apply knowledge of mathematics, science, and engineering;

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(b) An ability to design and conduct experiments, as well as to analyze and interpret data;
(c) An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability;
(d) An ability to function on multi-disciplinary teams;
(e) An ability to identify, formulate, and solve engineering problems;
(f) An understanding of professional and ethical responsibility;
(g) An ability to communicate effectively;
(h) The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context;
(i) A recognition of the need for, and an ability to engage in life-long learning;
(j) A knowledge of contemporary issues;
(k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Therefore, all these components need to be a part of effective assessment. PBL can easily be adapted to address all eleven outcomes of EAC 2007–08 Criterion 3 (EAC 3) [19]. Moreover, the purpose of PBL in engineering is to enable students to acquire applicable knowledge, develop team-working skills and skills for using computer technology, which will later help them to take part in more complex projects in the course of their studies and in their engineering careers. Therefore, assessment in PBL needs to use outcome-oriented assessment methods and process-oriented assessment methods, that could be formative or summative [20].

3. OUTCOME-ORIENTED ASSESSMENT METHODS (WHAT OUTCOME SHOULD BE ASSESSED?)

In outcome-oriented assessment methods the knowledge, acquired in a constructivist manner and the student's competences in independent reasoning and problem solving are assessed, rather than the ability to learn facts and principles. Since good knowledge in engineering requires a step-by-step approach to understanding and expansion of knowledge, the students' development is continuously checked and immediate feedback is provided on the correct results, on the material learned, and on the input of the individual student in comparison with other students. The teacher needs to pay special attention to problem formation, so that particular problems trigger a particular content, important for further understanding of engineering principles. For this reason, PBL in engineering requires smaller groups and more structuring by the teacher [2]. To stress out the importance of proper basic knowledge for the students (given in EAC 3a as ability to apply knowledge of mathematics, science, and engineering) we can use *a multiple-choice test* in PBL [21].

4. PROCESS-ORIENTED ASSESSMENT METHODS (WHAT PROCESS SHOULD BE ASSESSED?)

Typically process-oriented assessment methods in PBL include the assessment of the student's transferable skills, mostly independent-learning skills and problem-solving skills. To enable the students to gain a better insight into these skills within the new model of learning, we ask students to assess themselves. A *self-assessment* questionnaire helps them to identify their strong points and weak points. Students assess activities regarding group problem-solving process and individual search for additional information. The self-assessment questionnaire consists of items which can be arranged into one of the following four categories: planning and organization of learning; search for specific information; information transformation; information mediation. These categories correspond to the above-mentioned abilities (EAC 3k): to use the techniques, skills, and modern engineering tools necessary for engineering practice. These abilities help students to be engaged in lifelong learning (EAC 3i). With the self-assessment, students' progress in independent-learning skills could be observed [22].

As the groups are not tutor guided, *peer-assessment* constitutes a useful impulse and interior motivation for the groups, and also develops the students' peer-and self-assessment skills, which is important for their professional life. Peer assessment could be delicate: If peer ratings were used formatively, students either could not take them seriously or refused to complete them. If they were used summatively, ratings could be uniformly high and not useful [20]. For that reason, the peer-assessment questionnaire can include similar items as the self-assessment questionnaire, although another (not the same) scale is introduced in this questionnaire. We can use the following scale (as cited in [23, p. 553]): 'better than most of the group in this respect' (3), 'about average for this group in this respect' (2), 'not as good as most of the group in this respect' (1), 'no help at all in this respect' (0) and 'a hindrance to the groups in this respect' (–1) instead of marks from 1 to 5 for instance. Using different scales in both questionnaires helps to identify some rating errors by students, such as under-rate or over-rate of self-performance, avoiding giving extreme rates to others, hallo effect, different opinions among rating tasks, as reported by Sluijsmans et al. [24]. Both assessment results are an important indicator of the student's progress in the learning process and of the student's personal characteristics (e.g. an extremely negative self-image, or an extremely positive self-image) as well as of professional and ethical responsibility (EAC 3f).

5. OUTCOME AND PROCESS-ORIENTED ASSESSMENT METHODS

Three final outputs are used for assessing knowledge and skills for effective learning and problem solving in the PBL model: a portfolio, a written report and an oral presentation [25]. They could be used for formative or summative assessment. These outputs are connected with problems, especially with the final one called a 'problem project'.

A portfolio is a useful data collection for assessment of various abilities mentioned in the EAC 3 [26], [19], [27]. A portfolio could include the student's assignments, pointed to the overall input of the student, and to his/her personal development, minutes written down for appointments, and solutions of problems. It contributes to the assessment of abilities to design a process (EAC 3c), to function on multi-disciplinary teams (EAC 3d), to identify, formulate, and solve engineering problems (EAC 3e).

A written report includes the description of problem solving for a particular problem, the description of the work, the difficulties, the interpretation and the conclusions. In the assessment, considerable importance is attributed to the abilities to design and conduct experiments, to analyse and interpret data (EAC 3b). It also includes integration of different areas of engineering and interpretation of solutions, it partially shows students' understanding of professional and ethical responsibility (EAC 3f) and understanding of the impact of engineering solutions in a global, economic, environmental, and societal context (EAC 3h).

An oral presentation is designed as a public presentation of a problem, where each student in the group can present a part of the solution of a problem, and defend his/her contribution to the group's work. Students' ability to communicate efficiently in the field of engineering is assessed (EAC 3g).

The results of Kolmos and Holgaard show that it is difficult to assess, at an individual exam, complex knowledge calling for overview, argumentations, reflections and process skills developed in teams. Group-based exam might be more suitable to test these students' understanding [14]. Nevertheless, an individual exam is useful for measuring student's individual understanding of basic principles. Therefore, we created an assessment scheme in the PBL model that uses both: individual and group-based measurement instruments. They are classified in the three above-mentioned methods. Moreover, the assessment scheme addresses all of the EAC 3 components for engineering and follows new assessment methods in statistics, namely using a combination of assessment of projects, portfolios, case studies with the assessment of traditional exams and quizzes [28].

6. THE ASSESSMENT SCHEME FOR AN INTRODUCTORY STATISTICS COURSE

Statistics is considered as a methodological support to solve problems in various engineering fields where it is necessary to obtain the data and to statistically analyse them. Engineering statistics is a course, which aims to teach students how to think critically and how to solve engineering problems with the use of statistics. It is important for the students to understand the problem, to be able to find the data independently, to know how to use and process the data, and to analyse and interpret the results [22]. The characteristics of the PBL approach are stressed out in the new directions for teaching statistics [29]. Chance and Garfield [30] argued that in statistics education a strong emphasis is made on active learning, but more research is needed to determine an effective research methodology with alternative assessment. In our case, PBL was introduced as a model for teaching statistics within the existing syllabus for students of technical safety. We developed a series of problems, which trigger the learning process in statistics, and prepared our students to the new approach in teaching and learning.

In the PBL model students work in groups of five, each group solving various engineering problems. The course leads students from simple to more complex operations and tasks, both in terms of using computer technology and using statistical knowledge, which they have acquired through subsequent steps. Some problems are simple and can be solved in one day, others require one or two weeks, while the last problem requires a month work. At the beginning of the course, all five students in a group are required to solve a problem together; after that an individual student's contribution is needed to summarize the group's problem solution. Problems (cases) are designed by the facilitator. At the initial stage, problems are narrowly focused and require defined procedures to acquire the necessary knowledge. Thus, at the beginning students are guided, while problems slowly become more open-ended, meaning that students have freedom in searching for information and determining the course of problem solving. Problems should gradually prepare students to solve a 'problem project', described by Kolmos [31] as the most recommended and difficult project in project work. Therefore, we can say that incorporation of PBL in an introductory statistics course can help to perform effective project work into specific engineering fields later on.

In the assessment scheme for an introductory statistics course, evaluation of knowledge and skills for solving different problems and projects is very important. 'Although statistical reasoning might be assessed through one-to-one communication with students (e.g. interviews or observations) or by examining a sample in detail, in-depth students work (e.g. a statistical project), carefully designed paper-and-pencil instruments can be used to gather some limited indicators of students reasoning' [32, p. 24]. In order to develop students' reasoning, problem solving and transferable skills as much as possible, process and outcome-oriented assessment methods are not equally emphasised in the assessment scheme for introductory statistics [33].

An individual multiple-choice test is used as an outcome-oriented method. It measures only the basic statistical reasoning while complex problem solving is assessed in a group. The results of the multiple-choice test account for 25% of the total student's grade. The assessment scheme with impacts on final grades in percentages is presented in Fig. 1.

As a part of process-oriented methods students complete a self-assessment questionnaire with marks from 1 to 5 for each of the 12 items before and after the PBL model for introductory engineering statistics (separate sheets are provided). The peer-assessment (with the same items but another scale) is handed in after the end of the PBL model. We have opted for secret assessment, however we do allow for the possibility of naming the members as suggested in [23]. Since our students had no prior experience in assessment we decided not to include peer- and self-assessment results in students' final grade.

The most important in the assessment scheme are process and outcome-oriented methods, namely the portfolio including the assessment of 5 out of 7 problems in the PBL model, the written report, and the oral presentation of the final problem (called 'problem project'). They altogether account for 75% of the total student's grade. While a multiple-choice test is often used for assessment of knowledge and is easy for giving marks, assessing knowledge and skills in 'problem projects', where the three mentioned outcomes are required, is much more difficult in terms of assessment.

7. PURPOSE OF THE STUDY

To find out if 'problem projects' and the whole created assessment scheme allow for an appropriate assessment realization we posed the following research questions:

1. Does the assessment of 'problem projects' show significant difference in achievement of applicable statistical knowledge by students learning through PBL and students learning traditionally?
2. Is there any difference in evaluation of the PBL model and the traditional instruction using the same assessment scheme?

After the common characteristics of the PBL model had been defined and the methodology of assessment had been developed, the new approach was tested on students to verify the research questions.

8. METHOD

8.1 Participants

All students regularly enrolled in the second year of the engineering program of Technical safety at the University of Ljubljana were randomly divided into two groups: the PBL group, and the group which was taught by a traditional teaching method at the introductory statistics course. There were 38 students in each sample group, mostly 18 years old. Students were learning according to chosen approach for 15 weeks. During this period data were collected and the results were then compared.

8.2 Data collection

Both groups of students took a multiple-choice test, used to test the basic statistics knowledge. Students in the traditional instruction received the same problems as PBL students, but the problems were assigned at the end of the presentation of the statistical topics. Students in the traditional instruction were asked to solve the problems individually, following the teacher's instructions. They prepared a written report of the most complex problem ('problem project'), while the

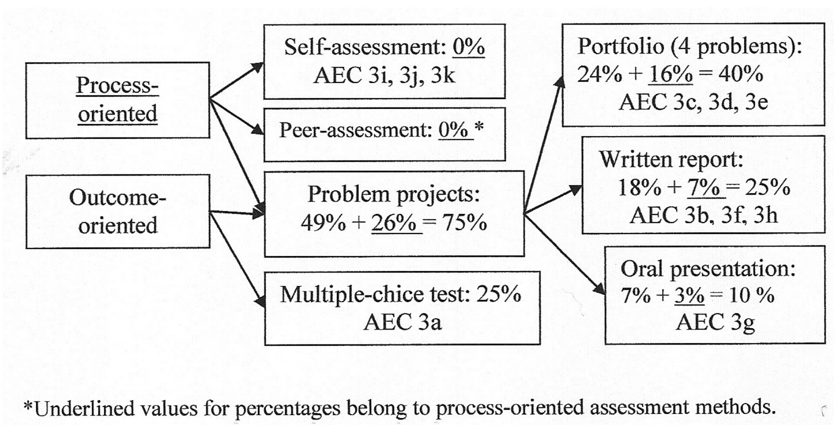

Fig. 1. The assessment scheme in the PBL model with impacts on final grade in percentages.

PBL group had to submit a portfolio presenting the solutions to five problems which they partially solved individually or as a group, and publicly present the most complex problem which was then assessed by two assessors. The teachers used a special assessment form and separately marked the written report and the oral presentation of 'problem projects'. 'Problem project' was the most important measurement instrument for assessing both: knowledge and transferable learning skills. The other instruments, such as oral presentation, multiple-choice test, self-assessment and peer-assessment were supporting measuring instruments.

8.3 Measurement characteristics of 'problem projects'

Groups of students were assigned a unique 'problem project'. In order to ensure the objectivity of 'problem projects' assessment, these 'problem projects' needed to share some common characteristics. They should be:

- Motivational (problems taken from engineering fields the students are interested in or problems, which are typical in their engineering profession);
- Unfamiliar and original (problems, which are not found in books, problems with fresh information and data);
- Unstructured (problems without sufficient data, students need to provide measurements or deliver questionnaires to get appropriate data);
- Open (do not have the right or wrong solution, the solution depends on the gathered data, chosen problem-solving process etc.);
- Require comparable statistics' work (namely finding appropriate data, organizing data, calculation of basic statistical characteristics, correlation, devising an appropriate statistical test, interpretations and conclusion).

For the purposes of experimental comparison of the PBL model with the traditional instruction we used the 'problem projects' presented in the Appendix. The problems of similar levels, which demanded the same kind of skills, had been previously assigned to students in the pivotal research to verify validity of such problems. It was concluded that the level of problems was adequate, since the students were able to retrieve relevant data to solve the task. Moreover, to be solved problems require appropriate statistical knowledge as well as transferable skills needed for statistics and engineering. By means of a special assessment form presented in Table 1 the 'problem projects' evaluated how much statistical knowledge and skills the students have acquired. For better objectivity students were informed about the assessment methods in advance and the written reports were assessed by two assessors. Their grades were comparable: the Pearson correlation coefficient was 0.96. But generally, there were some difficulties regarding objectivity and reliability of such instruments. Below we describe some of the difficulties we experienced in our pivot experiment [33]. Furthermore, we offer some advice on how to overcome these difficulties and to ensure better reliability of this instrument.

8.4 Difficulties in assessment with 'problem projects'

In spite of many advantages of teaching according to the PBL model we encountered some

Table 1. The assessment form of the written report with oral presentation for the 'problem project' in the field of engineering statistics

Content	In details	Max score
Statistics content (25%)	– design and conduction of experiment	8
	– calculations of measures of centre, spread etc.	2
	– algorithms of statistical hypotheses tests	3
	– calculations of statistical analysis	3
	– correlation	4
	– regression	5
Data 15%	– appropriateness (quantity) of measured (searched) data	5
	– finding and organizing appropriate data from relevant area of safety	4
	– correctness of data presentation (units, charts etc.)	1
	– judgment about data methodology, comparability and ccredibility	1
	– effort in data calculation and presentation	4
Engineering context 15%	– integration of statistics and engineering context in a problem	6
	– interesting sights in an engineering field, from which the problem is posed	4
	– the impact of solutions in a global, environmental and societal context	5
Report design 20%	– abstract, quality and visibility of report design	4
	– easily scanned calculations, clear inferences, conclusions	4
	– design of charts, tables, figures	4
	– text, grammar, references	4
	– made effort and work in written report as a whole	4
Interpretation 10%	– statistical inferences about null hypotheses	2
	– interpretation of inferences in safety engineering	3
	– conclusions about correlation of variables in safety engineering	2
	– suggestions for improvement of safety at the particular area in the future	3

difficulties in assessing knowledge and skills. Mainly the following can be pointed out:

- Assessment of individuals in a group;
- Objectivity of assessing unequal problems;
- Complexity of data search and data processing which are often hidden to the person, who assesses problems;
- Immaturity and irresponsibility of students to engage in group work;
- Getting assistance of a third person.

Assessment of individuals in a group. An individual contribution by each member of a group is especially delicate in group learning [34]. We organized assessment in such a way that the individual student's statistical knowledge and contribution to the group can be measured. A multiple-choice test measures an individual's basic statistical knowledge. Some problems are organized in such a way that an individual calculation of each member of the group is required in addition to a group written report. In the last problem, which is the most extensive, each student prepares an oral presentation and a defence of the work. Therefore, if one student does the work for another member, he/she has to teach this member how to defend the work. Problems' assessment is complemented by peer assessment and by a portfolio, which indicate the individual student's effort and contribution to the group work.

Objectivity of assessing unequal problems. Groups of students are assigned different 'problem projects' with a similar level of difficulty in order to prevent cheating. They encounter problems from various fields of safety engineering. A special assessment form, designed for better objectivity for different 'problem projects', consists of the following 5 categories:

1. Design and conduct of an experiment, correctness of process and calculations in statistical investigation (25%);
2. Appropriate data acquisition and organization (experiment design) (15%);
3. Integration of statistics in the field of safety engineering (15%);
4. Report design (20%);
5. Interpretation of calculations in the context of an engineering area, conclusions, suggestions for improvements in the particular area of safety engineering (10%).

These five categories were divided in 23 subcategories shown in Table 1.

Complexity of data search and data processing, which is often hidden. Open problems often lead students to unsuccessful search of data, inappropriate way of solving a problem, some difficulties in data collection, etc. An unusual way of solving the problem enables students to learn better and to go deeper into the nature of the problem. To describe all the difficulties in data processing and data search, students write minutes of meetings for the last 'problem project'. They add these minutes to their portfolio. This enables the teacher to get a better insight of the work which was done during the data search and the data processing phase.

Immaturity and irresponsibility of students to engage in group work. In the PBL model for engineering statistics, students provide self- and peer- assessment but the grades are not accounted for in the final grading. With the adoption of problem-based approach in other courses, such as English for specific purposes, ICT or mathematics teaching of peer-assessment skills could be included in these subjects. Thus, students might become more responsible for their contribution to group work.

Getting assistance of a third person. Several attempts have been made to prevent students from copying or getting assistance of third persons in the performance of 'problem projects'. Every effort is made in the design phase to prepare real-life 'problem projects', which would naturally generate the students' awareness that the expected statistical knowledge is needed for the solution of the problem and that the acquired knowledge is useful. The 'problem projects' are designed especially for the course. They include fresh information and data. A multiple-choice test is used to test the student's individual statistical knowledge important also in project work. Parts of the statistic knowledge from the 'problem project' are needed for other outputs in the portfolio, which is submitted by the end of semester and which reflects the continuous work of the student over the period of the entire academic year. Additionally, students are asked to publicly present and (or) defend their 'problem project' (to achieve higher reliability). All these steps are taken to ensure that the students are working on the problems themselves and to prevent recourse to different experts. Maturity of the students is also a factor we commonly rely on in the tertiary education, especially with alternative assessment of 'problem projects'.

9. RESULTS

We have already described that carefully designed 'problem projects' together with the special assessment form can be an effective measurement instrument for mature students. Additional measurement instruments, such as multiple-choice test, self- and peer-assessment incorporated in the assessment scheme, can enable a more objective assessment of individual student's knowledge and skills. In order to verify if such assessment shows significant difference in achievement of applicable statistical knowledge between students learning through PBL and students with traditional instruction, we analysed the scores for written reports of the 'problem projects'.

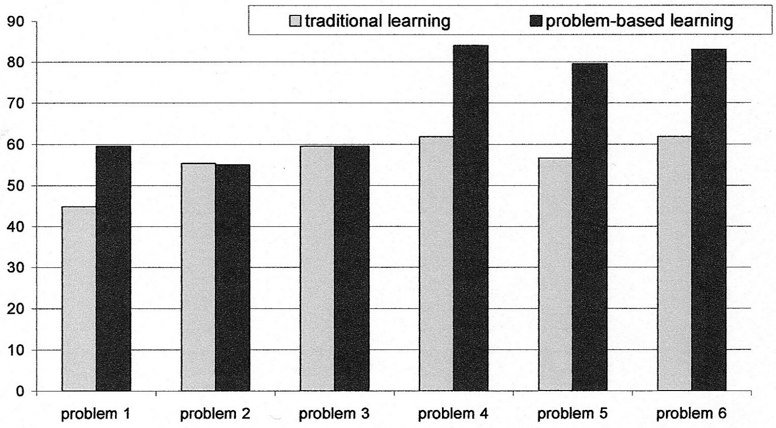

Fig. 2. Average scores delivered according to the assessment form in Table 1 across different 'problem projects' (in the Appendix) in PBL and traditional instruction.

9.1 Results for the research question 1

The teachers of both sample groups assessed written reports. The maximum score for the performed task was 100: 85 points for the written report and 15 points for the oral presentation. The quality of the oral reports was fairly good: none of the students was found to be unable to defend the written report. According to the two assessors (teachers in both groups) the reports were prepared by the students themselves, without any help of a third person. The total number of points gained with the written report was taken into account for the statistic analysis of the 'problem project'. We calculated the arithmetic mean of the points given to each student by both assessors. We used this score for the purposes of further processing.

The differences in the averages in scores across different 'problem projects' carried out by students within the PBL model and traditional instruction are presented in Fig. 2. A paired t-test was used because students solved different 'problem projects' and they had slightly different possibilities to get the highest score following the assessment form for assessing statistics through problems. The average scores regarding the same 'problem project' from both sample groups were compared. The paired t-test shows that PBL students performed significantly better in solving complex problems with 'problem projects' than those who were taught by the traditional method ($\mu = 13.42$, $\sigma = 10.92$, $t(5) = 3.011$, $p = 0.015$).

9.2 Results for the research question 2

We used the whole assessment scheme (shown in Fig. 1) for the evaluation of effectiveness of the PBL model in comparison to traditional instruction. With the described assessment scheme we evaluated:

- differences in the basic statistic knowledge among the students learning in a traditional way and the students learning with PBL (with the *multiple-choice test*);
- differences in solving complex problems (with *'problem projects')*;
- improvements of some learning skills, such as organisation and planning of the learning process, data retrieval, data transformation and data display strategies (with *self-assessment*);
- attitudes towards statistics instruction (with a *questionnaire about instruction*);
- attitudes to cooperative learning and the use of IT in learning statistics through the PBL model (with *questionnaires about teamwork and IT*).

The last two questionnaires were designed specially for the experiment. The results are shown in Table 2. First, it was found out that students engaged in the PBL model had gained sufficient basic statistical knowledge of understanding concepts, understanding principles, and basic linking concepts and principles emphasized by Gijbels et al. [8]. The differences were not statistically significant although students using the PBL model achieved higher scores at the multiple-choice test [33]. Second, PBL students got significantly better applicable knowledge and solved complex problems better than students learning traditionally. Third, students significantly improved transferable skills such as organisation and planning of the learning process, data retrieval, data transformation and data display strategies [22]. Fourth, students in the PBL model and students in traditional instruction assessed the instruction they were involved in. On the average, students of both compared sample groups were more inclined to choose the positive statements about the instruction. The scores of the questionnaire on the students' attitude towards instruction indicate that students in the PBL model experienced significantly more active methods of learning introductory statistics [35]. The absence of statistically significant differences in scores in other categories, such as motivation, difficulty and quality can be explained by several factors: a slightly changed method of traditional instruction because of the constraints of the experiment; an inadequately

Table 2. Evaluation of the PBL model with experimental comparison with traditional instruction

Students' abilities and attitudes	Measurement instruments	Attitudes in detail	PBL – TRADIT. differences	PBL end-beginning differences
1 Basic knowledge	Pre-test (PT)	Prior statistics knowledge	No difference	
	Multiple-choice test (MCT)	Concepts, principles	Positive dif.	
	MCT—PT	Improvement in statistics	**	
2 Complex problem solving	Part of MCT	Problem solving	**	
	Problem projects	Complex problem solving	**	
3 Transferable skills	Self-assessment	Planning and organization		**
		Search for specific information		**
		Information transformation		**
		Information mediation		**
4 Evaluation about instruction	Questionnaire about instruction	Active methods	**	
		Motivation	Negative dif.	
		Difficulty	Positive dif.	
		Quality	Positive dif.	
5 Students' attitudes	Questionnaire about teamwork and use of computer	Teamwork		Positive a.
		Use of computer—Internet		Positive a.
		Use of computer—Excel		Positive a.

** Significantly positive difference in favour to PBL at the 0.05 level of significance; detailed analysis can be found in Authors [2005], [2007], [2008].

chosen time for completion of the questionnaire; overburdened weaker students; and the use of previously unpiloted questionnaire and insufficient development of assessment skills. Fifth, students also expressed positive attitudes toward cooperative learning and the use of IT in learning engineering statistics [22].

Detailed information about the evaluation of effectiveness of the PBL model in comparison to traditional instruction with all measurement instruments used in the Table 2, such as statistical calculations and procedures exceeds the aim of this paper.

10. CONCLUSIONS

PBL can easily address all eleven outcomes of EAC 3 in engineering assessment [19]. However, much more effort is needed to apply an effective PBL model in an otherwise traditional university environment. One of the aims of adopting the PBL model in engineering is the organization of assessment in a way to encourage development of the students' abilities mentioned in the EAC 3 as well as to measure them effectively.

The presented organization of assessment in PBL for introductory engineering statistics fulfils all EAC 3 criteria for evaluation. The use of the assessment scheme brings a lot of work to the teacher and students.
However, students are motivated to work on real engineering problems and apply basic science knowledge to solve problems with cooperative learning. Gradually, more complex problems in PBL instruction prepare students step by step to deal with the final 'problem project', similar to a real engineering project. A written report, an oral presentation of 'problem project' and a portfolio of all problems create effective assessment of learning both, the learning outcomes and the learning process. Within the group problem-solving, a multiple-choice test and individual tasks allow for individual assessment in teamwork. Together with the self-assessment, the assessment scheme provides useful evaluation of knowledge and skills important for lifelong learning in the engineering area. Thus, difficulties to assess individuals in a group while solving 'problem project' could be reduced with other assessment instruments that are incorporated in a carefully designed assessment scheme.

The assessment scheme we used is an example of how to overcome the shortcomings of 'partial' PBL in some introductory science courses. Particularly, the assessment of 'problem projects' incorporated in the assessment scheme is sensitive enough to show the deficit of applicable knowledge and skills important for problem solving in groups. It could provide an objective picture of individual student's knowledge, skills and progress, if it is combined with other assessment elements from the scheme with the purpose of overcoming difficulties relative to group assessment.

The same scheme also serves as an evaluation of the PBL model in comparison with the traditional instruction. This evaluation is often missed in articles of engineering PBL. The experiment with randomly distributed students of technical safety showed that PBL students acquired sufficient knowledge and solved complex problems significantly better than students learning with traditional way of instruction. Similar results were obtained in the experiment by Senocak et al. [7].

Students of both comparable groups had mainly positive attitudes toward the instruction they were involved in. Positive students' attitudes about PBL are reported also in [9, 13, 15, 27]. However, the results of the PBL students in the present experiment did not differ significantly from students involved in traditional instruction. Moreover, the scores of peer- and self-assessment indicated insufficient instruction of peer assessment [33]. Therefore, PBL should be incorporated in some other introductory subjects such as English, IT or mathematics. This would help to give students more time to acquire self-assessment skills, so that they could assess their peers objectively and help the teacher to form the student's final grade.

In spite of the difficulties in assessment we want to retain the PBL model and are planning to implement it in mathematics courses where we have already designed motivational problems of all mathematical contents for some engineering fields. While there are some well profiled and pure models of PBL (we were particularly inspired by the PBL model used at the Maastricht University), we believe that PBL used in more 'traditional' university settings can have its advantages, too. In some subjects, e.g. mathematics, chemistry students joined also traditional lectures where they can profit from a contribution of structural knowledge, and PBL classes to increase motivation and develop students' critical thinking and lifelong learning.

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APPENDIX

'Problem projects' in the PBL model for basic engineering statistics.

1. BICYCLE TRAFFIC SAFETY. Because of numerous traffic jams in city centres riding a bicycle, a motorcycle or a moped is more economic than driving a car. But is it less dangerous? What is the *correlation* between the number of dead people in traffic accidents in Slovenia and the number of victims (riding a) of bicycle, motorcycle and motor accidents per year? Is the percentage of the DTS FCCT students, who wear a helmet while they are riding a bicycle, a motorcycle or a moped, *higher* than the percentage of students of other study programmes at FCCT?
2. DEATH TOLL IN ROAD TRAFFIC. What can be done to decrease the death toll in traffic accidents? Has the number of casualties in traffic accidents in Slovenia *significantly* decreased after the adoption of the 1998 Traffic law? What is the expected number of casualties for the *next few years* according to the available data?
3. FIRES IN SLOVENIA. Is Slovenia a fire risk area? What kind of danger do fires represent? Were fires *more numerous* before 1993 than after the 1993 Law on fire safety? What is the *correlation* between the number of fires and the fire damage?
4. STATISTICS AND SAFETY. Where can statistics be used in the field of safety? Are statistically based articles *less numerous* in the safety and health magazines than in other (technical) magazines available at the Central technical library in Slovenia? Has the use of statistics in the field of safety *been increasing* over the last years (judging from the specialised articles)? How fast has it been increasing?
5. FIRE SAFETY IN CATERING INDUSTRY AND IN TOURISM. Since when has the telephone number 112 been in use to call the fire brigade in Slovenia? Many foreign tourists to Ljubljana may not know which number to dial when they need the help of a fire brigade. This is why the heavier burden of responsibility lies on the safety officers. What is the *correlation* between the number of domestic and the number of foreign tourists in Ljubljana? Are the people, who are employed in catering industry and in tourism, and who do not know the emergency telephone number, *able* to use a fire extinguisher? (What is the *relation* between the people's acquaintance with 112-telephone number and the competence to use a fire extinguisher in a random sample of respondents?)
6. COMPUTER RELATED RISKS AT WORKPLACE. PC has become an inevitable tool in many workplaces. What are the requirements for a workplace with display screen equipment and what are the risks? What are the *trends* in the use of PC in Slovene firms? Does the eyesight of an employee at FCCT *depend* on the number of hours spent in front of a display screen?

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