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Impact of Problem-based Statistics Course in Engineering on Students' Problem-Solving Skills*

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In this comparative study, we examined the level of basic discipline knowledge and problem-solving abilities in problem-based learning (PBL), incorporated into a traditional curriculum in an introductory statistics course. Progressively less structured, less familiar and more open problems were presented to engineering students. Engineering problems triggered the learning of new statistical contents and activated small group problem solving. Students as a group determined the learning goals, individually searched for information, and together analysed the information collected. Such a problem-solving process with real-world problems is often seen as unstructured and time-consuming. An experiment was carried out to find out whether this approach yields adequate basic statistical knowledge and improves problem solving. Two randomised groups of students from the same engineering programme were compared: one group used PBL and the other followed the traditional method of instruction. The results of statistical analysis showed that engineering students with the PBL approach acquired sufficient basic statistical knowledge and were better able to solve statistical problems from the field of engineering than the students who followed the traditional way of instruction. Some characteristics of the implementation of the course are discussed, as well as some limitations of the study.

Keywords: undergraduate engineering; statistical knowledge, problem-based learning; problem-solving skills; comparative study

1. Introduction

Many engineering education institutions regard the acquisition of knowledge that can be retrieved and used in a professional setting, the acquisition of skills to extend and improve one's own knowledge and the acquisition of professional problem-solving skills as the most important for engineers [1]. Moreover, many researchers agree that it is a great challenge to incorporate an ever-increasing body of engineering knowledge and to develop the skills and attitudes necessary for effective professional practice without overloading or extending the curriculum [2].

Statistics can be seen as an important supportive subject in engineering education [3]. Moore [4] stressed that the most effective learning of statistics takes place when the content, teaching strategy and technology reinforce in a balanced manner and when the central idea of the new pedagogy is the abandonment of an 'information transfer' model in favour of a 'constructivist' view of learning. It became clear that for a good knowledge of statistics it is not enough just to absorb information and transfer the information from teacher to student; students need to learn through activities where the teacher encourages and guides the learning process and where problem-solving, higher order thinking skills and skills applicable to unfamiliar settings are among the main goals.

Engineering problems can be solved effectively with the application of statistical knowledge that includes knowledge about data acquisition and organisation, data transformation, data mediation and interpretation. Various transferable skills such as problem-solving skills, skills for effective use of information technology (ICT skills), independent learning skills and teamwork skills are exposed in statistical learning. These skills are helpful in solving engineering problems effectively and to lastingly improve one's own knowledge to be retrieved and used in a professional setting. However, due to a time-pressured curriculum (with limited time to learn non-engineering disciplines such as mathematics, statistics, etc.) teachers often feel unable to devote enough attention to developing the above-mentioned student skills. They are often afraid that their engineering students will achieve a relatively low level of knowledge of the discipline at the expense of the time used to develop skills.

In this paper we present a concrete method of learning that can improve problem-solving and other transferable skills without reducing basic discipline knowledge in the field of statistics.

We incorporated problem-based learning (PBL) into an introductory statistics course for engineering students. We have chosen the PBL approach, because we believe that it allows us to easily fulfil the above-mentioned Moore's goals for effective statistical teaching. We designed the careful sequence of real-world engineering problems, which triggered learning of a particular statistical content and showed the application of statistics in engineering.

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Without extending the existing curricula, we tried to improve the students' transferable skills and to teach students the basic statistical concepts that can be used in different situations in their future engineering career.

PBL is very suitable for engineering students [1, 5–9]. This learning approach is mainly used for teaching statistics at universities that have adopted PBL at the institutional level [10] or at advanced levels of studies, where an in-depth knowledge of statistics is required, with mature students [11]. Real-world problems in statistics instruction for students who are actively involved in small group problem solving, one of the important characteristics of the PBL approach, imply new roles for teachers in their interactions with students, including a focus on listening and observing and on asking questions to gain understanding and clarification [12]. Such problems in the context of engineering increase the students' motivation to learn [3]. Hjalmarson [13] provides a general picture of the various types of statistical measures that are familiar to first year students in engineering when they work on real problems, but fails to evaluate the individual's contribution in small group work.

'Unfortunately, most available studies of PBL in engineering provide only a very limited description of program design and no measure of implementation... Consequently, it is difficult to relate students' outcomes to changes in specific curriculum features or instructional practices and to know how PBL affects student learning . . . Therefore, despite the volume of literature on PBL, our knowledge about the effects of PBL on different outcomes, in different contexts and in different instructional designs is still limited' [14, p. 524].

The aim of the present study is to provide a more objective description of the effects of PBL on student knowledge. We describe in detail the organisation of PBL in the introductory engineering statistics course. We present a series of engineering problems that trigger learning of particular statistical content and describe learning process in which new knowledge is created, as well as skills that are emphasised and practised through it. Moreover, we present an experiment with randomised samples of engineering students and examine whether the problem-based approach yields adequate basic statistical knowledge applicable in different situations and if it improves problem solving in an average group of engineering students, burdened with a time-pressured engineering curriculum.

1.1 Acquiring knowledge and developing skills through PBL

The following contents are usually included in introductory statistics courses, however, they may appear in a different order: (a) probability; (b) probability distributions; (c) organisation and description of data and variables; (d) sampling, measures of centre and spread; (e) confidence intervals; (f) statistical hypotheses; (g) correlation and regression. Posing a not too difficult real-world problem to students before they acquire new knowledge can raise their motivation for work. We believe that students are, at least to some degree, acquainted with some statistical concepts that they come across in their every day lives (statistical terminology and graphs from newspaper articles), which helps them build new knowledge according to constructivist principles, which is the basis of PBL [15]. These principles are the central idea of new pedagogy in statistics whereby we need to change what students do from listening and reading to active participation: 'Students are not empty vessels to be filled with knowledge poured by teachers, they inevitably construct their own knowledge by combining their present experiences with existing conceptions' [4, p. 125].

In PBL, the problem takes the central role in the learning process and constitutes the motivation for the student's activities. It should be professionally relevant and as close as possible to real-life situations. Students are confronted with a problem prior to the acquisition of new knowledge. In order to be able to solve a problem, students must gain new knowledge corresponding to the definition of educational objectives of the curriculum. It is important for the students to integrate new knowledge in their own cognitive structures in order to establish a connection with the prior information [16]. Thus, the knowledge created can be used in new situations.

Students' active involvement in problem solving and the exchange of opinions in group work within PBL enable early detection of misconceptions in statistical knowledge. Even though there might be a poor structure of knowledge in the group work, this way of solving problems is the most common in an engineering career. If facilitators correctly support group work, giving appropriate feedback, and if they lecture on appropriate statistical structures offering useful assistance to PBL, this approach can be successful.

In PBL it is not sufficient to confront students with interdisciplinary real-world problems. Such teaching situations also need to prepare students to effectively and independently solve this kind of problems. Therefore, a lot of attention is devoted to improvement of three types of skills in problem solving: I—skills necessary to approach tasks and problems in a methodical manner (problem-solving skills), II—skills necessary to function successfully in tutorials (teamwork skills) and III—skills necessary to carry out individual activities (independent-learning skills) [17, p. 13].

Firstly, the facilitator introduces problem-solving strategies appropriate for solving statistical problems. A seven-step model has become established in PBL: (1) clarification of unclear terminology and concepts; (2) definition of the problem; (3) brainstorming; (4) list of possible explanations; (5) formulation of learning aims and key tasks; (6) independent search for additional information outside the group; (7) report, synthesis and testing of the new information. Steps (1) and (2) as well as steps (3) and (4) are often integrated to obtain 5 steps. Groups of students go through these steps in two meetings. Getting more and more open problems, students practise problem-solving skills with the help of the facilitator. In addition, students became gradually more familiar with problem solving in a small group.

Secondly, teamwork skills, which are supporting skills for effective problem solving in an engineering team, are practised. Statistical problems from the engineering field are often difficult for a single student, since problem solving involves a lot of different activities ranging from data collection, data management, sometimes even measurement or questionnaire management, computer processing, devising statistical hypotheses and displaying the interpretation of results. The right distribution of work among students can shorten the time for solving a given problem. In PBL some other positive characteristics of teamwork can be exposed and some negative properties can be reduced [18].

Thirdly, the facilitator in PBL presents the importance of independent-learning skills. Carefully chosen problems and setting up the groups' own learning objectives encourage students to search information and data from different sources (to reflect critically on the new information and to decide which information is useful), to transform statistical data, to provide simple and complex statistical calculation with some statistics programs and also to present the results and conclusions of problem solving. Since the problem does not give all the information, that students need to find the missing data and learn new facts from different sources (the Internet being an important one). Practising these skills with computer support in statistics is essential [19], not just for finding information but also for organising and transforming the information and for presenting the information in a suitable way.

1.2 Problems and problem solving through PBL

The facilitator first presents the skills and after that students practise them through solving the problem. Here is an example of a problem in PBL for learning probability distributions:

> *The number of reservations*
> American Air Flight 2705 from New York to Boston has seats for 120 passengers. Usually every passenger reserves a seat in advance. Because this particular line is very busy, usually all the seats are reserved. On average, 5% of people with reservations do not turn up, so American Air overbooks by accepting 126 reservations for 120 seats. Does the American Air company have the right approach in making overbooking? Explain. [20, p. 236; redesigned for PBL by Author].

The problem can be carried out in the following way (regarding the seven-steps).

> During the first meeting students should clarify unknown terms if any (1). They try to explain the nature of the problem in their own words, for instance: 'We need to find out, why American Air booked exactly 126 instead of 120 seats?'(2).They may search for the solution by making guesses about the reasons for the agency's policy (they try to connect the problem with their previous knowledge—probability calculations, Bernoulli trials) (3). After that they write down some facts, which can be calculated from the given data. They should conclude that there is a probability of 95% that a person who reserves a seat also comes on the plane and a 5% probability that a person doesn't come on the plane. With each reservation of the seat there are exactly two possibilities: the person may show up or they may not. Students might calculate the probability that among all 120 reservations exactly 1 person doesn't show up. They might do the same calculation for exactly 2 persons (3, 4 persons, etc.) not showing up. The use of a computer is a good option at this point (4). Students should set up the following objectives cooperatively: make a table of all possible issues with probabilities (distribution schema) to see all possible events, define the random variable connecting to this schema, find its characteristics (5). After searching for some additional information (in books) they might conclude that they have to deal with a binomial distribution. A facilitator has an important role to play: he or she asks questions, making sure the students are on the right track or helping them retrieve some prior knowledge about probability and so on.
>
> At home students should do all calculations to complete the tasks, using their own computer (or by hand). They should read about binomial distribution and find out some interesting features (6). At the next meeting, they find out that 6 is the mean for a binomial variable for the data given and that Air America does not have a good overbooking policy. A facilitator may pose additional questions to see if the students have got sufficient knowledge. For example, he or she can ask students to compute the characteristics for the binomial distribution with $n = 126$, to find out the probability that some passengers cannot be boarded because of overbooked seats (7).

At the beginning of a problem-based course students are usually confused if straightforward directions are not given. Some of them can simplify a problem and try to put all the given data into one familiar formula without critical thinking. Therefore, the facilitator plays an important role during

Table 1. Problems with specific characteristics in PBL for the introductory statistics course (see also the Appendix)

Problem	Number of reservations	Time needed to travel the distance to college	Concentration of flour in the air
Prior knowledge	Probability, Bernoulli trials.	Probability distributions, Basics about data, variables.	Sampling, Properties of a random sample, Normal distribution.
Cover contents	Discrete variable, Prob. Distributions.	Characteristics of data, Central limit theorem	Outliers, Point and interval estimation, Statistics inference.
Hours	1 + 1/2.	1 + 1	(2) + 2
EXCEL	BINOMDIST, CHARTS.	CHARTS, RANDBETWEEN	Internet search; CONFFIDANCE; Z-TEST
Details in portfolio	Characteristics of binomial distribution; Conclusions and interpretation.	Characteristics of data and sampling distribution; Differences (as well as in theory).	Point estimations, comparison with value in regulations; Confidence intervals–CI for small sample, Economy interpretation.
Method of work	All groups have the same problem; Students calculate probabilities for particular outcomes, find characteristics of binomial distribution and explain results.	Individuals provide their own data and characteristics. Groups of students change questionnaire and organise work to get new data for the sampling distribution. Groups of students analyse data and find distributions' differences.	Because one or two first measures are very high group of students have difficulties in comparing point estimation results with the value at Internet; After reading about CI for large sample they calculate it (for data of all groups) together with the teacher; Groups calculate CI for small sample.
Variations of problem	The same problem; The same data.	The same problem; The same data providing from individu.	The same problem; Groups different data.
Traditional instruction	Individuals solve the problem after teaching binomial distribution.	Teacher presents data, topic; Students carry out calculations after pattern recognition.	Teacher presents data, topic; Students carry out calculations at home.

Table 2. Problems with specific characteristics in PBL for the introductory statistics course (see also the Appendix)

Problem	Distribution of deaths due to diseases by age	Bicycles traffic safety (and similar problems)
Prior knowledge	Z-test, t-test.	Sampling, Variables, Distribution; Z-test, t-test, Chi-test.
Cover contents	Goodness of fit, Correlation.	Carrying out a small survey.
Hours	1+2.	1+2+2+2.
EXCEL	Internet search; NORMDIST, CHI-TEST; CORREL.	Internet search, CHARTS, CORREL Z-TEST, t-TEST or CHI-TEST.
Details in portfolio	Graphs showing frequency distributed data with fitting model of normal distribution; Calculations of chi-test for each individual as well for the group; Correlations, trend lines; Interpretation; Written report.	Retrieving relevant information and data; Description of the context area; Data modelling and display; Calculation of the basic statistical characteristics; Statistical inferences with statistical tests; Correlation and regression; Interpretation; Written report.
Method of work	After searching for the data on the Internet and appropriate methods as a group, students provide calculations for their own data. Comparison of individual and group results; Individual and group correlations; Findings important for health and safety.	After getting familiar with the problem area the group finds out what kind of data are needed; Carry out a questionnaire (measurement); Hypothesis testing and correlation of gathered data; Interpretation of the results and findings about safety ethic of Safety students; Written report; Presentation.
Variation of problem	The same problem; Individuals' and groups' different data.	Different problems.
Traditional instruction	Teacher performs appropriate steps of the test and solves a similar task; Students: homework.	The same as PBL students (without oral presentation).

this task by giving directions to students to concentrate on calculations and focus on possible outcomes due to overbooking. Students should realise why the concepts (e.g. distribution scheme of a random variable, mean, variance and other facts about probability distributions) are useful.

If a similar problem is given to students after the statistical topic has been presented, and after similar tasks have been solved by the teacher, students can solve the problem with less mental effort using similar sequences of calculation to the teacher. Thus, the problem becomes just a new exercise that can be solved with imitative reasoning [21].

To develop skills for problem solving and to achieve applicable knowledge in PBL we carefully selected problems for the introductory statistics course. These problems range from well-structured to ill-structured, from familiar to unfamiliar, from closed to open problems. Some of them are presented in Tables 1 and 2. The easiest problem in the Table 1 and 2 is well structured (have exactly the data needed for solving it, does not have any extraneous data), familiar (students often find such kind of problems in books) and closed (has exactly one solution) but, of course, the difficulty depends on the solvers' prior knowledge and skills.

2. Method

2.1 Purpose of the study

If we refer to Gagné's taxonomy of intellectual skills we can see that after the basic concepts have been understood and the rules have been applied this can lead to effective problem solving [22]. However, to deal with complex problems in engineering statistics, knowing concepts and rules is not enough; students must also know methods for solving such problems (problem-solving skills). To implement these they need to search independently for new information and data, transform these properly and interpret the results. These kinds of problems are practised continually through PBL. However, some authors argue that through this approach students solve complex problems better, but lack basic structural knowledge [23]. In order to find out whether, in teaching statistics, PBL yields better problem solving and sufficient basic statistical knowledge the following research questions (RQ) were devised:

RQ 1: What is the difference between fundamental statistical knowledge when students learn in a traditional way and when the students learn using a problem-based approach?

RQ 2: Do the students learning with PBL perform better in statistical problem solving (easy and complex) than the students taught in a traditional way?

To answer these research questions, a randomised experiment was carried out with undergraduate engineering students. The experimental factor (i.e. novelties introduced to the existing introductory statistics course) was in setting up problems that triggered learning of statistical contents via small group problem solving. First, an analysis of pivotal research was carried out in terms of the content and time-frame of the topics and tasks, the level of the given problems, the organisation of instruction, willingness of the teaching staff to assume the role of facilitators, the maturity of students to work independently in groups without tutors, and the system of assessment. After that, the central quantitative analysis with some elements of qualitative analysis was carried out for the purposes of the central comparative study.

2.2 Participants

The participants of the experiment were undergraduate engineering students at the University of Ljubjana, regularly enrolled in the Technical Safety study programme. The graduates of this programme mostly find jobs as technical safety engineers in different branches of industry. They were randomly distributed into two groups: the experimental group (PBL) and the control group (CON) with 38 students in each group. A PBL instruction with a shared tutor was offered to the students in the PBL group, while students in the CON group were taught statistics in the traditional way. During the first hour of instruction students were acquainted with the experiment and all agreed to participate.

2.3 Differences between the two educational formats

Both types of instruction followed the same programme and were organised in 2-hour weekly sessions during the second semester (16×2 hours for each educational format). Five successive problems from the field of technical safety were presented to both groups, however, different strategies for learning the topics was presented.

The PBL students were solving problems in groups of five members. The problems were presented at the beginning of a given topic. The teacher played the role of a tutor and facilitator simultaneously. For some time at least the facilitator became a member of the group and cooperated with the students as the so-called shared tutor. Students were also instructed to take over some of the tutor's tasks as suggested in [24]. With the first few tasks, the PBL students were still in the process of learning how to solve problems using appropriate steps in the problem-solving strategy. At this stage the facilitator assumed the leading role, students were practising problem-solving skills while working on the problems of probability calculus and probability distributions. At a later stage, students could draw on prior knowledge, based on their every day experience and on previously described topics, which allowed for a constructivist problem solving in a group. Each problem required more organisation of work and data handling, more complex information to be searched, organised, analysed and interpreted. Since good statistical knowledge, which is based on mathematical pillars, requires a step-by-step approach to comprehension and expansion of knowledge, the students' development was continuously checked. In 2-hour weekly sessions, the facilitator offered immediate feedback on the correct results, on the material learned, and on the input of individual student in comparison with other students. The first problems were short, simple, and more structured, but gradually the complexity of the problems increased. The nature of the final problem, termed as project task, was close to an engineering project that the PBL students had to present and defend publicly.

By contrast, in the CON group, the similar five problems were presented to students at the end of a topic that was taught. They were left to students as an individual (homework) exercise. Prior to solving a problem students in the CON were working on theoretical tasks with their teacher–instructor. In 2-hour weekly sessions, the instructor introduced and solved some typical problems during exercises. With this approach, students were encouraged to collect sample solutions and find similar problems dealt with by the instructor, or use textbooks, to solve their problem by pattern recognition. Students could solve the problem with less mental effort using similar sequences of calculation as the teacher. Therefore, for students in the CON the problem became a task. The instructor could give students feedback on right or wrong calculations but not on the appropriate way of thinking or methods used. The last problem was given to students in the CON group at the same time as those in the PBL but students in the CON were solving and defending their projects individually.

The instruction of the PBL approach implies a changed role of the teacher. While in traditional approaches the instructor does 'not pay special attention to growing diversity of students and cannot provide students with immediate and personalised feedback about their learning process' [3, p. 668], in PBL the facilitator can offer immediate feedback on the learning process in small groups.

Owing to the experiment constraints, the traditional instruction had to be slightly changed so as to acquire some elements of PBL. These adjustments were made in order to provide for equal conditions in both groups of students. Thus, students in the CON were solving similar, real-world problems as the PBL students; and their assessment was made of several components in order to evaluate the acquired knowledge and the process skills, which is otherwise a feature of PBL. On the other hand, the PBL students took a test, which is otherwise a characteristic of traditional instruction.

2.4 Measurement instruments and their characteristics

To obtain the answers to the research questions two different tests covering basic statistics, and various project tasks were designed.

To test the RQ 1 a multiple choice pre-test and post-test were designed in order to check whether the two groups differed significantly in their basic statistic knowledge. Both multiple-choice tests (with 4 or 5 possible answers) were sufficiently reliable according to the Kuder-Ricahrdson's formula ($r_{tt} = 0.71$ for the pre-test and $r_{tt} = 0.71$ for the post-test).

The pre-test covered combinatorics, probability and basic statistics, such as facts about the mean and reading information from graphs. Students had learned these contents at school before this course. The post-test included 40 tasks. They were ordered according to the seven statistical topics from the introductory statistics (written as (a) to (g)) and according to the types of learning outcomes. Three types of learning outcomes were analysed according to Gagné's taxonomy of intellectual skills [22, p. 62]:

- concept knowing (14 tasks)
- rule using (16 tasks)
- problem solving (10 tasks).

At least one task from each type was included in each statistical topic observed. The number of tasks regarding statistical content corresponded to the ratio of hours devoted to a given statistical topic in both models of instruction. The analyses of 10 tasks regarding simple problem solving were also used for RQ 2.

The RQ 2 about complex problem solving was tested with a project task, which was assigned to the students of both groups as the last problem in the course programme. Different types of statistical knowledge were assessed in the problem-solving process: the ability to retrieve professional information, the choice of relevant information, the integration of different content areas, data modelling and display, calculation of the basic statistical characteristics, statistical processing with statistical tests, correlation and regression; conclusions and the solution of the problem; the report writing, the presentation and defence of the report. This enabled a detailed distinction between the students' outputs. The problems of similar levels, which demanded the same kind of skills, had been previously assigned to students in the pivotal research, where it was concluded that the level of problems was adequate, since the students were able to retrieve relevant data to solve the task.

2.5 Data collection

At the beginning of the experiment, a pre-test with multiple choice questions was administered to all students. The test was completed by 24 and 25 students in the PBL and the CON respectively. The total number of points was 17, each point corresponding to one task. Students were not limited by time. The post-test was completed by 25 students of the PBL and 23 students of the CON at the end of the experiment, i.e. a week before the oral presentations. The time was not limited, some students were working on the test for more than two hours. The number of points was 40. In both tests the assessment was dichotomic.

Project tasks were chosen from different areas. Each group of five students was assigned a different project task that required data collection and statistical processing of the data. Groups were mostly formed according to the attractiveness of the project title for the students. The same project tasks were offered to students in the CON, but they were solving the tasks individually, meaning that five students were dealing with the same task. The time allotted for the project task was four weeks.

3. Results

In analysing the results we compared the achievements of both groups. First, we determined the differences in basic statistical knowledge of students learning through the PBL approach and the traditional approach. Secondly, we compared students' simple problem solving in both approaches, and thirdly, we pointed out the differences we obtained in complex problem solving and application of knowledge in project tasks. We performed statistical analyses using SPSS for Windows and rejected hypothesis tests at a significance level of $\alpha = 0.05$.

3.1 Analysis of differences in the basic statistic knowledge (RQ 1)

The score of the pre-test was determined for each student (Fig. 1). This score was corrected to take account of the possibility of guessing. After the correction, the lowest possible score was negative: –4.58. A student would obtain this score if all the results of the given tasks had been wrong. The maximum score of the pre-test was 17, one point for each task. In Table 3 a t-test was performed to test the statistical significance of the differences between the arithmetic means of the scores obtained in the pre-tests in both sample groups. The null hypothesis could not be rejected (t (47) = 0.686, p = 0.496).

Similarly, the score of the post-test was determined for each student. The lowest possible score was –12.5 and the maximum score was 40. Based on the statistical analysis of the collected data the null hypothesis on equality of population arithmetic means of post-test achievements in both sample groups could not be rejected (Table 3) although the p-value is quite small.

The individual progress of students was measured by the difference between the achievements in each

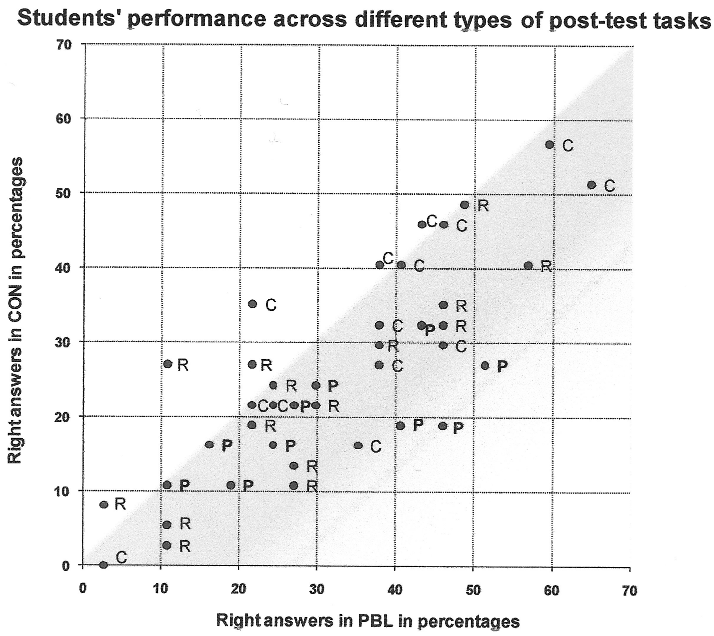

Fig. 1. Students' performance of different type of post-test tasks in the PBL and the CON. Intellectual skills in post-test tasks: C—Concept knowing, R—Rule using, P—Problem solving.

Table 3. Comparison of the PBL and the CON pre-test scores, post-test scores and the differences between the post-test and pre-test scores

	PBL group			CON group				
Data source	**Data**	**Mean**	**SD**	**Data**	**Mean**	**SD**	**t**	**p-value**
Pre-test	24	5.57	2.97	25	4.98	3.04	0.686	0.496
Post-test	25	14.22	6.46	23	11.10	6.03	1.729	0.091
Post Pre-test*	22	9.13	5.64	21	4.93	5.14	2.551	0.015

student's post-test and in the pre-test in both sample groups. The results for this individual progress, presented in Table 3, demonstrate that the PBL students achieved a more significant development of statistical knowledge than the students in traditional instruction.

3.2 Analysis of differences in problem-solving tasks (RQ 2)

In the post-test the students' performances in both sample groups was analysed according to three types of learning outcomes. This analysis indicates the types of tasks, in which the PBL students outperformed their peers in the CON (Fig. 1).

Table 4 includes the basic descriptive statistics and results of t-tests for groups of tasks included in the post-test. The average number of students in the PBL and the CON (in percentages), who gave the correct answer to the tasks testing concept knowledge did not differ significantly. The same can be claimed for rule using tasks. However, the average number of PBL students who gave the correct answer to the problem-solving tasks was statistically significantly higher than the average of students in the CON (t (13) = 2.783, p = 0.016). The PBL students performed better than students in the CON in all of the 10 problem-solving tasks in the post-test. It should be noted that the post-test measured only basic problem solving with short tasks, while knowledge and skills needed to solve more complex problems and to apply knowledge to real situations, were analysed by the project task.

3.3 Analysis of differences in complex problem solving with project tasks (RQ 2)

An analysis of project tasks in introductory statistics was carried out in order to observe the differences in complex problem solving and application of knowledge. The total number of points gained with the written report (maximum 85) was taken into account for the statistical analysis of the project task. The teachers of both sample groups separately assessed each written report. Their grades were comparable: the Pearson correlation coefficient was $r = 0.96$.

The first difference observed was the difference between the number of students who submitted and defended the written report. In the PBL group 28 students were involved in group work, and preparation of a written and oral report, as opposed to only 18 students in the CON group who participated in the same activities. According to comments in self- and peer-assessment, all PBL students except two cooperated very efficiently in a group work. This demonstrates a higher percentage of participation in the instruction and in the work among the PBL students, who were working according to PBL. The low-performing students in the PBL felt that they were more efficient and they were keener to take part in the work and instruction than their peers in the CON, where the work and learning were performed individually. When faced with complex problems, the CON students gave up sooner than their PBL counterparts.

The project tasks varied across groups and were slightly different from group to group according to the level of difficulty in retrieving useful information, doing calculations and providing interpretation (details of assessment in [25]). One of the 6 various project tasks was the following problem:

> *Bicycle traffic safety*
> Because of numerous traffic jams in city centres riding a bicycle or a motorcycle is more economical than driving a car. However, is it less dangerous in your opinion? What is the correlation between the number of victims in car accidents in the country and the number of victims riding a bicycle or motorcycle per year? According to LRTS-1, a helmet is not obligatory in traffic for everyone. Is the percentage of students in the Department of Technical Safety in the Faculty for Chemistry and Chemical Technology (FCCT) who wear a helmet while riding a bicycle, or a motorcycle, higher than the percentage of students in other study programmes at FCCT?

The project task *Bicycle traffic safety*, for instance, was carried out differently in each comparable group. Having detailed information of students' portfolio and written notes of the facilitator we can describe in detail how students from different learning settings dealt with this problem.

The PBL students tried to solve the problem using the seven steps.

> During the first meeting the students read the problem and clarified the unclear terms such as LRTS-1: The Law on Road Traffic Safety (1). They went through the questions and tried to find out what the problem asked for (2). Students discussed some facts that they already knew from the given context, and searched for some

Table 4. Comparison of the PBL and the CON correct answers per post-test tasks categories using paired t-tests (and Wilcoxon's signed rang tests)

		PBL group		CON group			
Intellectual skills	**No. of tasks (m)**	**Mean**	**SD**	**Mean**	**SD**	**t (T)**	**p-value**
Concepts knowing	14 (11)	10.50	3.12	8.71	2.70	1.623 (14.5)	0.117 (>0.05)
Rules using	16 (13)	5.86	3.24	4.50	2.73	1.297 (18)	0.205 (>0.05)
Problem solving	10 (8)	7.70	3.37	4.40	1.65	2.783 (0)	0.016 (<0.05)

interesting information and data about traffic safety on the Internet (3). The first question about overall safety of cycling was personal and students had a lot of experience from that field, so it was not problematic. The question regarding correlations also had clear directions what to do, while the last question was not so self-evident. Students wrote down some facts to show why riding a bicycle could be dangerous and they provided some data on traffic deaths in the country. They provided some data from which the correlation could be calculated (4). Students formed the aims for individual search (5).

At home students looked for additional information. They read about traffic safety in the country and found more information about the number of particular deaths per year. The data were found from different sources (the Internet, safety magazines, etc.) (6). At the next meeting the students shared the data collected, organised them, calculated correlations, trend line and started to design a report about some basic facts of traffic safety in the country. For answering the question on wearing helmets, the students in a group did not find suitable data on the Internet or other sources and, for this reason, they decided they had to prepare a questionnaire and carry out extra research among their peers. This extra search yielded another circle of the seven steps. Students had to create appropriate samples for two populations and define variables needed for statistical analysis. They corrected the questionnaire a couple of times after delivering it among their peers. After that, they did finally set up a statistical hypothesis and analysed the data with a suitable testing procedure. It took them two meetings. After the right interpretation of the test, they answered the problem. They thought critically about the results and interpreted the situation. The result (using an appropriate statistical test procedure) showed that the percentage of Technical Safety students wearing a helmet while riding a bicycle or motorcycle was not statistically higher than the percentage of other students at FCCT. The result was a surprise for the PBL students. They thought that students of Technical Safety are more aware of the benefits of wearing a helmet than their peers at FCCT because of their future profession. They suggested some possible explanations for the surprising result.

Students in the CON group were not so active. Two students out of five who signed for the project task *Bicycle traffic safety*, gave up and did not prepare a written report. Of the remaining three students a tendency to cooperate was also observed. To ensure equal conditions in both groups this claim could not be denied. Although, particular students were not so good:

> According to the calculations in written reports, we could find that students did not find as many data as students in the PBL group for the second question regarding correlation. They did not organise the data for correlation appropriately. The third question regarding wearing a helmet was the most difficult for them. They did not realise the need to create their own questionnaire and provide a statistical test to answer the question. After the teacher's suggestion to make a questionnaire students asked 25 students of Technical Safety and 25 students in other FCCT programmes if they owned a helmet. More students at Technical Safety answered that they own a helmet. Therefore, the CON students concluded that the percentage of students at the Department of Technical Safety at FCCT who wear a helmet while riding a bicycle, or a motorcycle, is higher than the percentage of students on other study programmes at FCCT.
>
> Students made a few mistakes in their procedure. They asked students if they own a helmet and not if they wear a helmet while riding a bicycle. (Some students can have a helmet but they might not wear it, some students might not ride a bicycle or motorcycle, so they do not need a helmet.) Moreover, students generalised the results without appropriate testing. The interpretation was of course insufficient.

The same project task was posed to one PBL group with five members and to five students from the CON. Thus, pairs of groups of five students were given the same project task. Therefore we decided to compare group achievements with the paired t-test. The average score was calculated for students in the PBL and the CON who were working on the same project task and came up to the end. This score was referred to as the group achievement. We found out that the group achievement for a given project task in groups in the PBL was statistically significantly higher than in the CON ($t\ (5) = 3.011$, $p = 0.015$). Differences in the problem *Bicycle traffic safety* were not an extreme case, which can be seen in [25].

4. Discussions

Teachers erroneously believe that students (at the beginning of tertiary education) will be able to deal with complex problems just by doing exercises from textbooks, where open problems are very rare [26]. Students need to get the chance to learn how to solve real open problems effectively. On the other hand, dealing with such problems is time-consuming. This is why many teachers in a time-pressured curriculum believe that students lack basic discipline knowledge in problem-based instruction.

In this paper we presented the PBL approach in a time-pressured engineering curriculum, in which students were gradually prepared to solve open, unstructured and unfamiliar real-world problems. We carefully selected the problems to trigger learning and constructivist students' group work. Special attention was also given to an immediate information feedback provided by the facilitator. This is very important for students not involved in highly structured instruction in order to learn basic knowledge of not encyclopaedic courses typical for engineering [1]. The teacher's feedback gives students information on the adequacy of their thinking process and appropriate understanding. We analysed the differences in the students' basic statistical knowledge and problem solving in PBL and in the traditional approach through a pedagogical experiment.

Some comparable studies on PBL and the traditional approach were examined in the meta-analyses in [23] but all the experiments included in the investigation dealt with PBL in the field of medicine, except one in vocational education and one in economics. In general, only a few scientific articles have been published dealing with the comparison of the PBL approach and more traditional approaches in engineering [6, 8, 14, 18, 27–29]. The authors in [8] and [27] reported differences in students' knowledge measured before and after the PBL innovation incorporated in the traditional approach. Analyses in [18] and [28] showed differences in skills improvement in both educational formats, [14] showed differences in motivational beliefs, self-regulations and study strategies, the study in [29] showed differences in creativity. Only one study [6] examined knowledge gathered in both educational formats. According to this study students learning with the PBL approach presented better knowledge about gases in the field of chemistry than students who learned in a traditional way. In the field of teaching statistics at various school levels and study programmes, most of the scientific papers centred on qualitative analyses of small group problem solving with non-comparable studies [3, 12, 13].

Our experiment has some shortcomings. We need to point out the relatively small numbers of students involved in randomised comparable groups, although we included all students in a given engineering programme. The present study also lacks analyses of qualitative methods, such as in [12]. To overcome this shortcoming, in the future we plan to videotape the PBL learning process and to interview students. The fact that we did not have the same teacher working in both groups could also be regarded as a shortcoming, because it could lead to the conclusion that the differences between the two groups can simply be attributed to differences in the teaching effectiveness of the two teachers. But this kind of difference cannot be completely eliminated because even in the case where the same teacher worked in both groups, student success might depend on the teacher, namely the teacher may prefer one instructional method, and would consequently be less efficient in using another method of instruction. We decided to opt for two different teachers, because in our case the same timescale of instruction in both groups was very important due to time-table constraints. Despite the above-mentioned shortcomings, we can put forward the following conclusions.

5. Conclusions

The described experiment showed that the integration of PBL into an introductory statistics course for undergraduate engineering students in study groups of up to 40 students is suitable for improving students' problem solving and other skills as well as for achieving sufficient knowledge of the discipline. Except for a few students' comments that this kind of work is too demanding, most of the students were satisfied with it and very motivated to be actively involved in real-engineering problem solving.

The statistical analysis of the pre-test and the post-test results shows that the students who learnt introductory statistics with PBL achieved comparable basic statistical knowledge to those students who learnt by a traditional way of instruction. Providing statistical analysis of individual progress of students, which was measured by the difference between the achievements in each student's post-test and in the pre-test in both sample groups, the results demonstrate that the PBL students achieved even more significant development of statistical knowledge than the students in traditional instruction. The results of the post-test indicate that PBL students presented similar achievement at concept-knowing tasks and rule-using tasks, although they were significantly better at achieving problem-solving tasks.

Complex problem solving, which demanded a certain level of basic statistical knowledge and problem-solving skills (which were measured by the post-test), as well as independent-learning skills such as planning, organisation of learning, data search for specific information, skills of data transformation and data mediation, was measured with project tasks. Development of independent-learning skills, important in solving real-world complex problems, were analysed separately. The statistical analysis performed on project tasks from the field of statistics in engineering yields the results that suggest that students using PBL are better able to solve complex statistical problems and that they can apply their theoretical knowledge more efficiently than the students who were taught by the traditional method of instruction. In the previously described project task *Bicycle traffic safety*, students in traditional instruction did not tackle the problem as completely as the PBL students did. The PBL students interviewed a larger sample and fulfilled the conditions for statistical analysis. Their interpretations were broader and more detailed.

The results may encourage other teachers to incorporate the elements of PBL into their own courses, but the problems should be carefully selected and should be adapted to the course contents and to the time available, as well as to the students' prior knowledge and the type of their future carriers.

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Appendix

Engineering problems in problem-based learning for introductory statistics course

Time to needed to travel the distance to college

Please, fill in the following questionnaire! The questionnaire is about the relationship between the distance to school and your final grades.

- Year of birth
- Final grade achieved in the 1st college-year
- The most frequent way of transportation
- Postcode of the city of your residence
- Distance between residence and college
- Time to travel the distance

Your group should determine the types of variables from the questionnaire and describe suitable presentation and calculation of measures of the centre and spread! Analyse the data of all students for the following variables: time and the last digit of time. What can you say about distributions of these variables?

Often the questions in questionnaires are not designed appropriately. They may be suggestive, unspecific, biased, etc. For example, the answer to the question about time could be just a rough estimate, or the time the student spent on a particular day, someone might write down a longer time to support the influence suggested in the first question. For this reason, in statistics the questions need to trigger answers that result in a set of comparable data. How would you need to formulate a question to obtain the exact time a student needed to get to the college, and what kind of theoretical variable would represent these types of data (the last digit of data)? Pose this new question to your peers and summarise the data.

At home prepare 50 random samples of size 4 from the data collected from the last variable. Examine the means of all 50 samples and explain the nature of this new sampling distribution! Compare it with the distribution of student's last digit of the exact time! Explain the differences!

Concentration of flour in the air

Your group is going to measure the concentration of flour particles in the air during practical exercises. Make a first measurement with the school apparatus and compare the result with the border value from the Rules on protecting workers against risks from chemical substances (http://www.uradni-list.si/1/content?id=33886). Take measurements every 5 minutes. How does each new measurement influence the estimation of the real value and influence your conclusions?

Estimate the concentration of flour (from practical exercises) for your sample with the degree of confidence 95% (99%) and explain whether the air in the apparatus is appropriate for a real workshop environment or not? What do you think about the economic aspect of the measurements? Is working in such an environment still safe for workers or not? Prepare a 5-minute presentation on your findings.

Distribution of deaths due to diseases by age

Use the data from the Statistical office of RS and describe the properties of statistical variables: age of death of the citizens caused by disease 1 (2; 3; 4; 5, 6, 7) in the years A (B; C, D, E) in our country. Is the statistical variable measuring the age of death of the citizens caused by disease 1 in any year (assuming that the conditions in health services, citizen standards, etc. have been unchanged) normally distributed? Compare the frequencies of your variable (1, A) with the frequencies of the variable that measures the deaths caused by disease in the year B. Interpret the results.

As a future engineer of health and safety at work write a report about the risks for death caused by a particular disease and make predictions for the future.

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