THE IMPACT OF PROBLEM-BASED LEARNING ON STATISTICAL THINKING OF ENGINEERING AND TECHNICAL HIGH SCHOOL STUDENTS

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Engineering statistics teachers are often faced with two problems: time pressure and the lack of curriculum guidelines. This report presents two cases from Slovenia, illustrating how the problem-based learning approach can be applied in engineering education at university level and in high schools. This approach enables activities which encourage statistical thinking and improve students' problem-solving skills, teamwork skills as well as skills for effective use of information technology (IT) even with a time-pressured curriculum. The report describes organization of engineering problems, which all trigger learning of statistics in a typical introductory statistics course as well as organization of engineering problems (cases) which connect statistical contents with some other subjects in technical high school curricula (such as sociology, IT, mathematics). Furthermore, the results of students' success through problem-based learning are provided.

INTRODUCTION

Teachers of different engineering fields often complain about a time-pressured curriculum. They have to teach many engineering contents and develop important engineering skills, such as how to efficiently solve real-life problems, how to use various IT supports, as well as how to work in a team. All these abilities and skills are emphasized also in teaching of statistics. Moore pointed out that the most effective learning of statistics takes place when content, pedagogy and technology reinforce each other in a balanced manner. He made a clear statement that for a good statistics knowledge 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 one of the main goals (Moore, 1997). Group work, feedback and open-ended problems can support learning. Chance and Garfield (2002) stimulated researchers and teachers to cooperate and apply this theory in practice. Guidelines for Assessment and Instruction in Statistics Education (GAISE) college reports provided some recommendations on how to implement the new teaching strategies in secondary and tertiary education.

Mathematics teachers who also teach statistics as a part of mathematics in secondary schools often face difficulties, regarding lack of time for learning statistical contents at school, incomplete statistics education of mathematics teachers, and lack of curriculum guidelines (Accrombessy, 2006). In Slovenia, these difficulties are presented at the secondary and tertiary levels. The curriculum for prospective mathematics teachers at University of Ljubljana (the largest university in Slovenia) did not contain statistics as a compulsory subject until the new Bologna reform. Moreover, since Slovenia did not have any study programmes of statistics until the academic year 2002/2003, most teachers of statistics at the tertiary level in Slovenia are not statisticians. These teachers need good guidelines for teaching statistics.

Problem-based learning (PBL) fulfils the mentioned goals for effective statistical teaching despite the described difficulties. It can be suitable for engineering education (Perrenet et. al., 2000). PBL is not applied just at many engineering universities with completely renovated curricula, which are entirely based on solving practical interdisciplinary problems; it is often adopted at traditional universities with disciplines' based curricula, thus changing only the teaching methods in some courses (de Graaff & Kolmos, 2003). Although the modalities of the practical application of PBL differ, the important characteristics of this approach are described as follows (Bound & Feletti, 1998, p. 2): PBL is an *interdisciplinary approach* (1); PBL is based on *problems from a real-life situation* (2); PBL activates *cooperative learning* in a small group (3); PBL enables students' *critical thinking* and learning through *problem solving* (4); PBL encourages students to

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use various sources for learning (5). These characteristics are also very important factors in engineering and in teaching statistics.

(1) *PBL* is not discipline based but rather an *interdisciplinary approach*. Namely, PBL curriculum is centered around problems and not on academic disciplines. Problems *in engineering* also integrate knowledge of some basic disciplines (mathematics, chemistry), special engineering fields (energetic) and supportive fields (economy, ecology). Moreover, problems *in statistics* usually require knowledge of statistics (and mathematics), statistical software skills (SPSS, MATLAB), and knowledge from a specific field (energetics, safety) which provides the general context for the given statistical problem. Knowledge in this specific field is important for the appropriate data collection and interpretation.
(2) In *PBL*, *problems in a real-life situation* trigger learning of the given content and constitute the motivation for the student's activities. Solving problems in a real-life situation is also needed in everyday *engineering* practice. Additionally, *statistics* can serve as a tool for solving problems from various research fields.
(3) In *PBL*, students solve problems in small groups, where *cooperative learning* is encouraged. *Engineers* also need to work cooperatively in a team, since teamwork is very often essential in professional practice. Group work is also very important for teaching *statistics*, because statistical problems usually require various types of work: measurement, data retrieving, statistical computation, calculation of statistical analysis, interpretation and display of results. All these tasks are difficult to carry out for a single student. The performance in the tasks is increased if they are previously discussed in a group.
(4) In the *PBL*, students activate *critical thinking and problem-solving skills*. At the beginning of the problem-solving process students should draw on their prior knowledge, whereby possible ways of problem solving and the gaps in knowledge are determined. After identifying the gaps in knowledge, students define learning objectives needed for solving the problem. The first 5 steps in a problem solving process, namely: clarifying unclear concepts, defining the problem, analysing the problem (brainstorming), posing possible explanations and formulating learning objectives, are usually carried out in the first meeting. Such steps emphasize students' critical thinking. They are not just the key components of PBL, but also an important activity in *engineering* as well as in *statistics* problem solving.
(5) In *PBL*, students search for additional information individually from *various sources* and synthesize all the knowledge to solve the problem in a group. These 2 steps are carried out in the second meeting in the problem solving process. The teacher is not a source of new information. He is a facilitator, who assists the students in the learning process and develops the students' independent-learning capacities. *Engineers* should also use various sources, such as reference books, Internet, standards and various software programs to find appropriate information. Moreover, various sources are important for teaching *statistics* to find appropriate data. Statistical software is essential for statistical calculations and mediation of information.

PBL requires changes in the assessment system. Integrated knowledge, knowledge applicable in a real-life situation, problem-solving skills, team-working skills and independent-learning skills (with effective help of computer technology) should be assessed rather than the student's test-writing skills. If some of the components are not assessed the students will not learn them. This knowledge and the transferrable skills are essential for students' critical thinking and life-long learning. They are activated through the PBL process and continuously checked by the facilitator.

INCORPORATION OF PBL IN COURSES OF ENGINEERING STATISTICS

We incorporated PBL in statistics for future engineers at the secondary and the tertiary level. In both cases, we tried to develop students' critical thinking across various problems from real-life situation that triggers learning of a particular statistical content. Statistical reasoning and critical thinking are often seen as the most important elements in statistics education at all levels of statistics teaching. Statistical thinking can be seen in the connection between data analysis and probability, in the inference from sample to population and in the differences between theoretically "nice" cases and real-life problems.

In the first case, we integrated PBL model into an otherwise traditional engineering education. We introduced the PBL model into the introductory statistics course for future engineers of technical safety. In the second case, we introduced a cross-curricular 4-year project called Energy as a value at a technical high school in Novo Mesto. The ongoing project involves several subjects at school and the common thread for the PBL activities in teaching statistics.

PBL IN THE INTRODUCTORY STATISTICS COURSE

PBL was incorporated in a one-semester introductory engineering statistics course at the University of Ljubljana. The course was aimed at future engineers of technical safety (30 hours, 2 hours per week). It included typical topics: probability (a); probability distributions (b); organization and description of data and variables (c); sampling, measures of centre and variation (d); confidence intervals (e); correlation and regression (f); and statistical hypotheses (g). Lecturing on appropriate statistical structures offered useful assistance to the PBL. An engineering problem was presented at the beginning of each statistical topic. Students solved problems in groups of five members. They usually followed the 7 steps in problem solving process. With the first few problems, the students were still in the process of learning how to solve problems using appropriate steps. At this stage the teacher assumed the leading role; students were practicing problem-solving skills while working on the problems of probability calculus and probability distributions. At a later stage, students could draw from prior knowledge, based on their everyday experience and on previously described topics which allowed for a constructivist problem solving in a group. Students' development was continuously checked. The teacher took over the role of a facilitator and offered immediate feedback on the correct results, on the material learned, and on the input of individual student in comparison with other students.

Series of problems that encourage critical thinking in the introductory statistics course

The first problems were short, simple, and more structured, but gradually the complexity of the problems increased. Each problem required more organization of work and data handling, more complex information to be searched, organized, analysed and interpreted. This means that two or several meetings were needed to go through all the 7 steps of the PBL cycle. It took students between one week to one month to solve each problem. The easiest problem was well structured (had exactly the data needed for solving it, did not have any extraneous data), familiar (students often find such kind of problems in books) and closed (had exactly one solution), but of course, the difficulty depends on solvers' prior knowledge and skills development. Problem solving in the first problem did not necessarily involve computer use, but after solving several problems, computer use became inevitable since a considerable amount of data processing was required. In the initial stages data search was more or less guided by the facilitator. However, in later stages, students performed this activity on their own. The nature of the final problem was close to an engineering project which the PBL students had to present and defend publicly. Each group of students dealt with one problem. Problems varied across PBL groups, but they demand similar skills and abilities (which were examined also for evaluation), namely integration of different content areas, data modelling and display, calculation of the basic statistic characteristics, statistical processing with appropriate statistical tests, correlation and regression, solution of the problem and interpretation.

The time frame and characteristics from (1) to (5) for the problems, which were assessed in a student's portfolio, are presented in the Table 1.

The first column in Table 1 shows a series of *engineering problems from a real-life situation* (1, 2). Problems motivate students to learn a particular *cover content* and to carry out the *teamwork activities* (3). Students should use *prior knowledge* to activate *critical thinking* and discussion in a group. They should find out, which information and statistical content knowledge is important in the particular *problem solving* process (4). Each new problem demands more *time* for the problem solving process (regarding the 7 steps). Furthermore, each new problem is more complex regarding *various sources* that need to be used in order to solve the problem (5).

Active students' participation in problem solving process of gradually more complex problems from a real-life situation enables students' development of critical thinking. Learning of facts and routine exercises are left for individual work at home. At the instruction, a minor amount of time is needed also for an introduction (to teach the probability), for the explanation of the 7 steps method), and for additional explanation or comments on statistical contents.

Table 1. Problems and their characteristics in the introductory statistics course for engineers

Problem	*Connection with prior knowledge*	*Cover contents*	*Time*	*Sources*
The number of reservations	Probability; Bernoulli trials	Discrete variable; Probability distributions	1+1/2	No Internet, Data given; BINOMDIST, CHARTS.
Time needed to travel the distance to college	Probability distributions, Data, variables	Characteristics of data; Measures of centre, spread; Central limit theorem	1+1	No Internet, Data measured; CHARTS, RANDBETWEEN
Concentration of flour in the air (as in a bakery)	Properties of a random sample; Normal distribution	Confidence intervals	(2)+2	Internet, Data measured; CONFFIDANCE; Z-TEST
Distribution of deaths due to diseases by age	Z-test, t-test	Goodness of fit; Correlation, regression	1+2	Various Internet sources; NORMDIST, CHI-TEST;
Bicycles traffic safety (and similar problems)	Sample, Variables, Distribution; Z-test, t-test, Chi-test.	Hypothesis testing; Carrying out a small survey	1+2+ 2+2	Various Internet sources; Data measured; EXCEL

PBL COMPONENTS AT THE TECHNICAL SECONDARY SCHOOL

The new mathematics curriculum 2008 for secondary education in Slovenia prescribes only 10 lessons (school hours) out of the total of 560 mathematics lessons to learn statistics. In such a short time teachers need to teach students: the basic statistical concepts and types of data (a); how to collect, organize, and display relevant data (b); various measures of centre and variation and simple relations between variables (but the correlation is not explicitly pointed out) (c); to apply statistical knowledge in a holistic statistical investigation of an interdisciplinary problem (d). Students should choose an area of investigation, they should pose research questions, collect and organize data, analyse them and interpret the results. The teacher alone should choose the appropriate time for teaching statistics. According to the general recommendation the statistics course should be integrated in the first year curriculum of the secondary education, while the combinatorics and probability should be integrated in the third or the forth year. Teachers are free to choose the appropriate time for statistical contents and find a suitable coordination between subjects in a holistic statistical investigation. Since Slovene teachers do not acquire perfect statistical knowledge in their qualification period, the freedom to choose the appropriate period for learning statistical contents and for organizing interdisciplinary connection is not an advantage.

At a technical high school, Novo Mesto School Centre, a kind of grammar school specializing in mainly technology-based subjects, teachers found an elegant solution in a cross-curricular project integrating several subjects within the course. 93 first-year students from three classes participated in this project, called Energy as value. It involved 4 modules, one for each school year: Rational usage of energy, Transformations of energy, Energy and a traffic, How to reduce energy consumption. The project became the framework for statistical teaching. For each module we designed one statistical problem that could trigger learning of a particular content, typical for the PBL approach.

Series of problems that encourage critical thinking at secondary education

In the new learning strategy inspired by the PBL characteristics, the teacher introduces a statistical problem to the students in a class. Teacher assumes the leading role in teaching the steps of the problem solving process and in learning the appropriate statistical contents. Students provide the aims for further work together with the teacher. Students individually collect and organize data through the year outside the curriculum hours, but some extra time is devoted to the problem solving process and discussion about the posed problem in school’s curriculum, so teachers can spend some additional lessons dealing with statistical contents. The time frame and characteristics from (1) to (5) for the statistical problems of the project are presented in the Table 2.

Table 2. Problems and their characteristics in the technical secondary school

Module and problem	*Connection with subjects*	*Cover contents*	*Time*	*Sources*
Year 1: Rational usage of energy	IT - informatics	Basic statistical concepts, types of data; How to collect, organize, display relevant data; Measures of centre, variation	10 hours for statistics	Measurement
Year 2: Transformation s of energy	Chemistry, Physics	Relations between variables; Interdisciplinary approach of a particular problem	Hours for physics + project week	Measurement
Year 3: Energy and a traffic	Math: Combinatorics Probability	Connection between data analysis and probability; Normal distribution	Hours for combinatorics, probability	Creation of a questionnaire and inquiry
Year 4: How to reduce energy consumption	Sociology	Steps of statistical investigation; Inference from sample to population	Project week + hours for sociology	Creation of a questionnaire and inquiry

Table 2 shows that students have the opportunity to be actively involved in *a real-life* problem incorporated *in* an *engineering* module (2). Thus, there is an *interdisciplinary connection between* statistics and at least one curriculum subject (and with several curriculum subjects across the module) each school year (1). *Small group work* is not explicitly pointed out, but the teacher encourages cooperative learning (3). Students have opportunity to deal with the problem from different perspectives (sociology, physics) and this could improve students' understanding of a particular content. With an extra *time* left for statistics and with a cross-curricular interaction, *statistical thinking* is exposed (4). The teacher is not the only source of information. Students should use *various sources.* Moreover, they measure data themselves to get the appropriate information (5). They also learn how to critically select information from various courses. This would not be possible, if they learned only from one handbook.

In Slovene curriculum, statistical thinking is hidden or intertwined with other subjects (such as sociology) or left to students themselves in a holistic statistical investigation, which is many times left for students' work at home. Instead of only *teaching* the curriculum contents (a), (b), (c), and (d), problems in the project also activate students' *critical thinking*. They help students to achieve some broader goals: to *understand differences* and characteristics among various types of data (a'); *to formulate questions that can be addressed with data* and to collect, organize, and display relevant data *to answer them* (b'); *to select and use appropriate* statistical methods to analyze data (c'); and *to develop and evaluate inferences and predictions that are based on data* (d'). These goals are in line with the standards of the National Council of Teachers of Mathematics for teaching statistics at the secondary level.

EVALUATION

Evaluation in the case of the introductory statistics course was done in two steps. First, a pivotal research was carried out to check the content and time frame of the topics and tasks, the level of the given problems, the organisation of instruction, the willingness of the teaching staff to assume the role of the facilitators, the maturity of students for independent work in groups, and the system of assessment. After that, the central experiment was carried out. The students of the Department of technical safety at University of Ljubljana, regularly enrolled in the second year of the study programme, were randomly distributed into two groups: the experimental group and the control group. There were 38 students in each group. Students in the experimental group were offered the PBL instruction 2 hours per week during the second semester, while their colleagues in the control group were learning statistics in the traditional way at the same time.

The full analysis of the experiment was presented in the dissertation (Drobnič Vidic, 2005). In our report we highlighted the results that address critical thinking and problem solving. Student's statistical thinking and problem solving was exposed in the student's portfolio, student's self-assessment and in a presentation and a public defence of the last problem. The analysis of self-assessment was thoroughly exposed in Drobnič Vidic (2008).

Self-assessment marks indicated that the PBL students in introductory engineering statistics significantly improved their competences in planning and organization of learning, search for specific information, information transformation and mediation (Drobnič Vidic, 2008). Only 10 out of 300 marks did not indicate progress through PBL. All these independent-learning skills and life-long learning skills have become essential in the rapidly developing world of science.

From the student's portfolio teacher could grasp the way of student's critical thinking. In the portfolio, the PBL student specified the performed problem solving process for all the problems in the Table 1, his / her individual contribution, difficulties regarding problem solving and individual interpretation of the results. The portfolio included also the minutes of the group work, written down during group meetings, occasional inappropriate ways of problem solving and doubts during the problem solving process.

The last (most complex) problem in Table 1 was taken for the purposes of comparison between the experimental and the control group. Statistical analysis of these problems yielded results, which demonstrate that the PBL students were able to solve complex problems better than the students, who were learning with the traditional method of instruction (paired t-test across the same problems: mean (SD) = 13.42(10.92), t (5) = 3.011, p = .015). The PBL students received higher marks because they applied their statistical knowledge better into the real engineering situation and they used skills necessary for data search for specific information, skills of data transformation and data display more efficiently than the students learning traditionally. Details of previous analyses can be found in Drobnič Vidic (2005).

Evaluation in the case of the technical high school is not finished yet. At the time of this report, half of the 4-year project has been completed. The impression of teachers is very good. The experience of interaction and cooperative work performed by the teachers was positive for most of them.

CONCLUSION

Incorporation of the PBL in engineering statistics increases student motivation for learning because they can see benefits also in engineering applications. A lot of attention should be paid to a careful selection and design of the PBL problems from engineering fields, time distribution, and connection with other contents if we want to engage students effectively into active learning of the appropriate statistical content. Improvement of transferable skills, such as teamwork and independent-learning, problem-solving skills in a real-life situation can hopefully improve critical thinking and problem solving and discharge time pressure in other engineering courses of undergraduate education.

REFERENCES

Accrombessy, F. D. (2006). An Evaluation Study of the Process of Reform of Statistics Teaching at the Secondary Level in Benin: Assessment and Perspectives. In A. Rossman &. B. Chance (Eds.). *Proceedings of the ICOTS-7, Salvador, Bahia, Brazil*.

Boud, D., & Feletti, G. I. (Eds.) (1998). *The Challenge of Problem-Based Learning* (2nd ed.). London: Kogan Page.

Chance, B., & Garfield, J. (2002). New Approaches to Gathering Data on Student Learning for Research in Statistics Education. *Statistics Education Research Journal, 1*(2), 38-44.

De Graaff, E., & Kolmos, A. (2003). Characteristics of Problem-Based Learning. *International Journal of Engineering Education, 19*(5), 657–662.

Drobnič Vidic, A. (2005). *Problemsko zasnovan študij pri proučevanju inženirske statistike: disertacija (PBL in engineering statistics: dissertation).* Ljubljana: Filozofska fakulteta.

Drobnič Vidic, A. (2008). Development of Transferable Skills within an Engineering Science Context using Problem-Based Learning. *International Journal of Engineering Education,* 24(6), 1071-1077.

Moore, D. (1997). New Pedagogy and New Content: The Case of Statistics. *International Statistical Review, 65,* 123-165.

Perrenet, J. C., Bouhuijs, P. A. J., & Smits, J. G. M. M. (2000). The Suitability of Problem-Based Learning for Engineering Education: Theory and Practice. *Teaching in Higher Education, 5*(3), 345-358.