Learning model for developing critical thinking and encouraging innovativeness in engineering education by problem based learning

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Abstract. *Paper scopes on learning model whose final aim is to obtain pre-service engineering education teachers transformation from the university level to the primary school level affecting student's design thinking and innovativeness. For this purpose, the model is based on problem-based learning. The proposed approach was executed at the university program level for elementary teacher program at Technical studies with didactics course in 201/2018 studying year at the University of Ljubljana. A laboratory exercise where students make paper gliders by using the presented learning model is described. Learning model begins by instructional design and problem challenge task which is followed by a problem solving task. Students were divided in five groups where gliders relevant concept knowledge was varied before solving the problem was initiated. Students showed group cooperation and discussed possible problem solutions before production. All groups could improve paper glider model to gain better functionality when loaded. The groups with a higher knowledge given were more successful however we could not observe a higher degrees of innovations at any group. Students are predominantly oriented toward finding a trivial solutions and rather gain experiential knowledge before deducting known one to a given case.*

1 Introduction

The number of problems is growing rapidly whereas their complexity increases [1]. Technological knowledge alone will not be sufficient to solve rapidly changing problems [2]. Education can prepare students to successful adaptation to the changing world by teaching them to be critical thinkers. These skills enable students to effectively analyse multiple sources of information, draw logical conclusions, and create new innovativeness [3]. Critical thinking is deeply processing knowledge to identify connections across disciplines and find potential creative solutions to problems [2, 3]. Critical thinkers use decision-making and problem-solving skills to analyse situations, evaluate arguments and draw appropriate inferences [3].

Nowadays, students have not enough research-oriented, interactive and collaborative learning experiences. Learning content should be more motivational. We have to strive to discourage passive learning environments that discourage learning motivation, and do not promote lifelong skills. All this can be achieved by using active teaching methods, the inductive methods like problem based learning. Besides that, students have to collaborate and actively engage in the learning process [4].

Education has long be criticized for not promoting creativity, innovation and technology, and that there is a little student involvement of their authentic experiences in learning process [5]. Making products is being strongly emphasised in technology education. Student's attention is focused on material they are manipulating, instead on creativity, technology, and innovation [6]. Primary school education should follow society demands and produce people who are proficient in basic skills, are prepared to learn new things, collaborate in solving problems, and can produce innovations [7]. There are many definitions for innovation. It can be defined as a significant improvement, refinement or introduction of something new. Innovation and creativity are significantly different. Innovativeness cannot occur without creativity, however creative thinking is not necessarily innovative [6]. Creativity is the ability to produce ideas, processes or product that are novel, original, imaginative, unexpected, and useful [6], meanwhile innovation include changes. Result is a useful product or process that is commercialized and widely spread. Students have to have open design tasks and learn knowledge and skills to be able to create innovative solutions [6].

At the Faculty of Education in Ljubljana, we educate primary school trainee teachers. In the 4th year of the undergraduate study programme, technology content is included in Technical studies with didactics course (TDC). The course consists from lectures (15 h) and laboratory exercises (30 h). In-service primary school teachers cover technology content from the 1st to the 5th grade of the primary school education. Before the undergraduate study the students have last had technology content in the 8th grade of the primary school. Big time gap results in a very poor technological knowledge. Existing knowledge is inadequate, unstructured, unrelated and with many misunderstandings of the basic technological concepts. The TDC main goal is that undergraduate students acquire all the necessary technology knowledge and skills for technology teaching. In the academic year 2017/2018, we carried out part of the laboratory exercises in accordance with 21st century competencies [4]. In particular, the development of innovative thinking was highlighted. In addition to acquiring technological knowledge, skills, and competencies, we aim to encourage primary school teachers to innovate and to develop innovative products. Our goal is the production of new, original and useful products, and moving away from reproduction of simple and trivial solutions products. To gain innovativeness we need to achieve critical thinking and problem solving. In the following a learning model based on problem based learning is presented for a hands on laboratory exercise.

2 Method

The proposed learning model consists of 5 phases, Fig. 1 and is based on different teaching methods and our previous findings, Tab. 1. Laboratory exercise starts with understanding the problem by giving students a challenge by instructional design (ID), 1st phase (challenge). Students produce a simple product by a given plan that is relevant for the field of contents. Phase output is critical thinking. Application, analysis and evaluation process are enhanced in providing cause related to consequence (CC) answers while working in pairs and test in advance given product functionality. To be able to gain innovativeness students must have a deeper contents knowledge. This is provided in the 2nd phase (knowledge). E-learning material can be used. If students already have a satisfactory knowledge level the phase can be skipped. The longest phase is the 3rd one (problem) where a challenge from the 1st phase is graduated to more realistic, actual and real life however at the same time limited the given time possibilities. Although this phase is based on problem based method it rather a mixture of inductive methods with the purpose to emphases technological functionality and usability essence. The functionality to gate the minimum solution level and the usability to gain optimization level. This enables determining the best product solution and stimulates towards innovative solution products. The method used in 3rd phase combines challenge-based learning (CBL) and discovery based learning (DBL). Students gain knowledge through resolving a problem based on their past experiences (phases 1 and 2). But, it is not CBL, as the problem is not open-ended. Further the used method can be seen as a mixture of problem-based learning (PRBL) and project-based learning (PJBL). It enables students to use critical thinking, available resources and technology. The role of the teacher is assistant or tutor. The starting point is a problem with unclear solution that requires original solutions from students. Students are active participation of the learning process. But, it is not PRBL as the problem is not opened and students do not have to study the literature and search for information to solve the problem. The solution to the problem is not theoretical, but a concrete product. The method is also not a PJBL as the problem is fixed in advanced and the solutions to the problem do not rely on the students' interests [9]. In 3rd phase each student

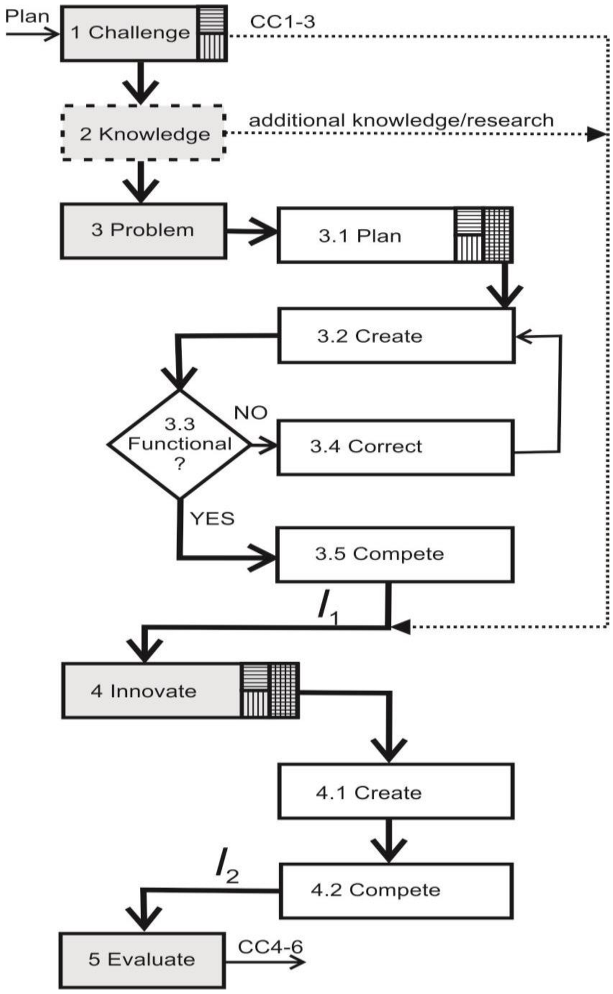

Figure 1. Proposed learning model, where CC- cause related to consequence answers, *l*- measure for functionality/usability.

In a pair produces their own draft product solution whereas the final solution is expected to be a mixture of both drafts with strong arguments behind.

Planning must start by setting the functionality criteria. Students gain the in advance product functionality set by correcting feedback loop until they do (sub phases 3.2-3.4). The phase ends with a competition to determine the best solution based on the usability measures. The most trivial usability is defined by graduate increasing load of the product solution. Once the 3rd phase is completed students gain new knowledge from all the different solutions produced. Due to simplicity of the problem product solution students are expected to obtain clear CC relations towards product functionality and usability. In the 4th phase (innovation) our learning model objectice is that students take into account best 3rd phase product solution, determined CC in the 1st phase and assimilation of the additional given knowledge into a new product solution being an upgrade to the 4th phase best solution thus gaining innovativness. While in the 3rd phase students can test functionality freely and use new material to make a product solution in the 4th phase students use only the given material and do not test their functionality nor usability. This is done by a laboratory exercise conductor. The final, 5th phase (evaluate) is to present innovative solutions that are evaluated. Clearing the content concepts, and relations. Inductive reasoning to deduction stimulating critical thinking is enhanced. Students are asked to provide additional CC answers. Learning model ends with meaningful learning.

To measure critical thinking level a pre-test and a post-test are suggested encompassing multi-choice questions covering the higher three revised Bloom's Taxonomy levels (analyse, evaluate and create). Students' innovativeness is product related and group dependant assessed with a five-point scale, where 1 means no innovativeness and 5 means very innovative.

3 Results

Paper glider product is used in the proposed learning model. It is related to primary school curriculum (technology content). It is one of the most typical product where primary school teachers' lack of concept knowledge related to product functionality/ usability.

In the 1st phase students made an origami glider according to a given plan (longer side of A4) and material (A4 paper sheet). Functionality (gliding) was tested by glider hand throwing and obtaining the average gliding length. In pairs they provided answers regarding the causes for the difference in gliding distance (CC1- point of glider holding, CC2- throwing direction (up, straight, down), CC3- throwing velocity (push, slow, arm stretch)).

In the 2nd phase students were divided in five groups (G) where e-learning materials with information regarding gliders relevant concept knowledge was varied, Tab. 1. G1 skipped phase 2. G2 and G3 received e-learning material (aircraft definition, glider model components, gliding principle and glider examples), where G3 lacked of gliding principle. G4 and G5 both had additional insight into the problem understanding by expanding 1st phase challenge where glider plan changed (shorter side of A4 paper sheet) and possible usage up to 10 paper clips for glider balance. The purpose was to determine whether inductive active work results better than passive e-learning material reading. G5 additionally received the whole e-learning material.

In the 3st phase a problem was presented to students: build a model of paper glider that fly at least 4 m

Table 1. Variation of e-learning material, where *N* – number of students in the group, AD- aircraft definition, GMC- glider model components, GP - gliding principle, GE - glider examples.

Group (*N*)	Expan-ded phase 1	*Conceptual knowledge & examples*			
		AD	GMC	GP	GE
1 (6)	/	/	/	/	/
2 (9)	/	1	1	/	1
3 (5)	/	1	1	1	1
4 (14)	1	/	/	/	/
5 (11)	1	1	1	1	1

straight and carry a load of 30 g (functionality). Students could use two A4 paper sheets, scissors, adhesive tape or paper glue, and up to 20 paper clips.

In the 5st phase students provided answers regarding gliding distance difference (CC4-what increases gliding distance, CC5- what decreases gliding distance, CC6- what is difference between throwing a glider or a dart).

72 students took TDC whereas results are given only for students who solved both the pre-test and the post-test. The sample represents 45 students (6.66 % of male students and 93.33 % of female students).

3.1 Critical thinking

Critical thinking was assessed by pre/post-test. The reliability of the test used was demonstrated by the coefficient Cronbach $\alpha = 0.63 > 0.60$. One-way variance analysis (ANOVA) did not show statistically significant differences between groups on the pre-test (F=0.73, df=44, α=0.58). Statistically significant differences were found between groups on the post-test (F=5.11, df=44, α=0.002). The Games-Howell post-hoc test showed statistically significant differences between the G2 and G4 (α=0.004) and between the G2 and G5 (α=0.000). On average, the G2 group reached the higher score ($\bar{x}$=5.67; s_x = 0.87), the G5 reached the lowest ($\bar{x}$=2.36; s_x =1.69), the G4 reached 3.07 points (s_x = 2.08).

Table 2. Gain (Δ) of knowledge in percentages by groups where the process dimension is tagged by 1-6 and the knowledge dimension is tagged by A-D.

Question (RBT)	Δ_{G1}/%	Δ_{G2}/%	Δ_{G3}/%	Δ_{G4}/%	Δ_{G5}/%
1.1 (C5)	0.0	33.3	0.0	7.1	-8.1
1.2 (C5)	-50.0	-1.1	-20.0	0.0	-81.8
2.1 (D4)	0.0	0.0	-80.0	7.1	-9.1
2.2 (D4)	0.0	33.3	0.00	7.2	-18.2
3.1 (D4)	-17.7	22.2	-80.0	0.0	-9.1
3.2 (D4)	0.00	0.0	-80.0	0.0	18.2
4.1 (D4)	-66.7	44.4	0.0	-21.4	-35.8
4.2 (D4)	-16.6	33.3	20.0	-28.6	-45.4
5.1 (D4)	16.7	44.5	0.0	-21.4	-36.3
5.2 (D4)	33.3	33.3	0.0	-28.5	-63.6

Questions are classified according to the revised cognitive Bloom's taxonomy (RBT), Tab. 2. It can be seen that G2 made the most progress in their knowledge while G5 made the least. For most questions, an anty-progress is evident. For other groups, very little progress in knowledge is noticeable.

3.2 Innovativeness

In assessing innovativeness, we have taken into account the characteristics of an innovative product [5], adjusted for our needs. We focused primarily on usability of paper gliders (gliding length according to load weight). We also considered number of modifications and the degree of modification: (1) without noticeable similarity to given examples, (2) in connection with theory, (3) without obvious connection with examples and theory, (4) exceeds the given framework, (5) completely

Table 3. Lengths of paper gliders by group and its subgroups in percentages and degree of innovativeness.

Group	l_1/ %	l_2 / %	Degree of innovativeness
1.1	75,0	112.5	2
1.2	100,0	112.5	2
1.3	100,0	150,0	2
1.4	62.5	75,0	1
2.1	0,0	112.5	2
2.2	80,0	125,0	2
2.3	37.5	50,0	1
2.4	112.5	112.5	2
2.5	150,0	87.5	2
3.1	112.5	100,0	2
3.2	37.5	75,0	2
3.3	87.5	80,0	1
3.4	25,0	75,0	1
3.5	37.5	62.5	1
4.1	87.5	112.5	2
4.2	100,0	125	2
4.3	100,0	112.5	2
5.1	107.5	37.5	2
5.2	37.5	100,0	2
5.3	100,0	62.5	3
5.4	147.5	152.5	3
5.5	125,0	27.5	2
5.6	125,0	25,0	2
5.7	102.5	102.5	2

different model shape flying the most loaded the longest distance. Tab. 3 shows gliding length (l_1) and improved glider model gliding length (l_2) for G1-G5 with its subgroups (pairs). Most groups made a functional paper glider in the 4th learning model phase. G5 was the most successful (average l_1 length) in 3rd phase - gray fields and G4 in the 4th phase - gray. Degree of innovativeness is below average ($\bar{x}$= 1.87; s_x = 0.53).

G1 and G4 exhibit understanding difficulties between glider and paper glider model (no additional knowledge in phase 2). Student's solution drafts were issuing from the origami plan. Most G1 and G4 students made glider's fuselage by using a triangular, circular or cone profile. Paper gliders were mostly of two pieces (fuselage and wings). Wings were similar to those of the origami glider. In phase 4, most students made only simple improvements: the position of the load, the shape of the wings, reinforcement of the fuselage etc.

For G2, G3 and G5 (additional knowledge in phase 2) a low level of innovativeness has been observed ($\bar{x}$= 1.88; s_x = 0.60). Paper gliders were similar to the examples. However, it was noticed that students had taken into account given additional knowledge regarding gliders. Improved glider models of these groups have horizontal and vertical stabilizers.

4 Conclusions

Although students exhibit low level of innovativeness a high level of application has been detected. Students are inclined towards finding a trivial solutions. Overview of existing products in the technology field is welcome, the analyse of these products can lead to a fixation of thinking and over reliance on already-produced products [10]. Knowledge gained from the learning material helped students to understand what a glider is, how it is working and what its components are. During the laboratory exercise, students made a little progress in their knowledge. The greatest advancement in knowledge has been unexpectedly made by G2 (additional knowledge without explaining the gliding principle), while G5 showed most decline in measured knowledge by pre/post-test though most additional knowledge was given in the 2nd phase of the proposed learning model. For other groups, progress is minimal, negative, or not at all. The presented model was a novelty for the students. They had the most difficulties in the 3rd (problem) phase of the learning model with the planning sub-phase and further in the 4th (innovate) phase. Students could hardly find more than one improvement that was predominantly a very simple one. Nevertheless concerning also a very short time given for the exercise execution (1,5 hours) obtained results do promote to use the proposed learning model to encouraging innovativeness.

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