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Self-directed learning of engineering design by pre-service teachers using innovative ICT-based approaches

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ABSTRACT: The 21st Century has brought unprecedented change, especially in education. Gaining competence in the traditional school subjects is no longer enough. There is a need to supplement the acquisition of science and technology knowledge with more general professional, interpersonal, and self-directed learning skills through primary and secondary education. Lifelong learning has become increasingly prevalent for pre-service teachers. In 2017, the Slovenian Government launched a national project to address the question: How can a university transform its pre-service teacher study programmes with self-directed learning using innovative digital technology? As a result, the author designed and implemented a model of the innovative use of technologies in technology and engineering courses. An experiment was conducted over a two-year period with 95 pre-service teachers. Through the model, effective self-directed learning is enabled using technologies to enrich higher cognitive levels and also to develop an ability to create and modify design tasks.

INTRODUCTION

The 21st Century technological environment has deeply affected all spheres of our lives and created a need for continuous learning and re-learning [1]. Moreover, it is essential that learners be given an opportunity to develop broader skills, attitudes and suitable approaches for sustainable or lifelong learning. The 21st Century learner will need to be highly self-directed and the teacher/instructor more the learning facilitator, thus moving away from traditional classroom teaching [2]. The capitalising on virtual reality, an increased emphasis on practical skills and practising teachers are all now part of academia [3]. Self-directed learning might be enhanced through modern information and communications technology (ICT). This allows atypical learning experiences that encourage pre-service teachers to engage in metacognitive reflections about their experiences learning with different types of technology [4]. Self-directed learning experiences are worthwhile in teacher education and experiences framed explicitly around ICT may reinforce a positive bias toward using technology for effective teaching and learning in a real-world context [4].

Pre-university technology and engineering education is a developing academic discipline that stems from the need to improve the education of engineers to cope with future challenges [1]. An important aspect is that primary and secondary school technology and engineering teachers be able to realise their potential through differentiated curricula [5]. Unfortunately, teachers very seldomly employ ICT-supported experimental activities to enhance deeper learning and skills development [6]. The use of digital technology in education is rather limited to its intuitive use at the first level of Bloom's taxonomy (3rd sub-level), as pointed out by Hilton [7]. In pre-service teachers' education, ICT is rarely used for significant task redesign or for the creation of a new task [7]. Early teaching/learning in direct manipulation environments is better associated with real technological challenges, and students gain more transferable knowledge, skills and experience [8], especially in performance-oriented tasks [9].

In 2017, the Slovenian Ministry of Education, Science and Sport issued a tender for an 18-month pilot project to introduce new and innovative ICT-based approaches for all national university study programmes. This aimed to improve pre-service teachers' digital and technological competencies by acquiring ICT skills and teaching practice. Pre-service teachers wishing to maximise their use of emerging technology need to plan for, and reflect on, technology integration in their classrooms. The use of ICT at lower educational levels is necessary to meet student needs and learning objectives at higher levels. This provides guidance for future directions and improvements.

SELF-DIRECTED LEARNING AND ENGINEERING DESIGN

A concept of self-directed learning as a metacognitive process was developed during the past 50 years. The common features of all variations is of a process in which individuals take the initiative in diagnosing their needs, formulating learning objectives, identifying resources, choosing and implementing appropriate learning strategies, and evaluating the learning outcomes [2]. To cope with challenges due to the accelerating rate of technological change, lifelong learning has been recognised for many decades as critical for teachers. Self-directed learning requires students to take ownership (responsibility) of their own learning, to become agents (act independently) in the learning process, to engage in active learning and to enjoy the satisfaction of learning [10]. Within higher education, student perceptions are beneficial in evaluating the nature and quality of educational interventions [11], especially where ICT-supported instructions are implemented [4].

Technology and engineering curricula include many active learning modes, e.g. problem-based learning, project-based learning, critical thinking, inquiry-based learning and high-impact practices [12]. These active learning modes might increase self-directed learning, but the effects for individual students vary substantially [1]. Some learned concepts and processes may be understood through the components inherent in events and effects that emerge from the interaction of the events [13]. Different representations are used to help the learner learn, especially when model-based explanations and problem-solving are used [14]. The author decided to focus on the essential outcomes of a technology and engineering curriculum, i.e. an ability to design. When designing, a reduction of uncertainty in the design results from the following characteristics of a design [15]:

- design problems are always subject to conditions;
- conditions are benchmarks for making the final decision about a solution;
- a design problem is often a decision-making problem;
- information management is crucial in reaching a satisfactory solution;
- a design problem is a real-world problem and the solution is physical;
- design problems do not have a single solution;
- design theories have a high degree of abstraction and the best solution is an ideal design, which is arrived at by systematically applying advance design theories in which engineering problem-finding skills seem to be more important than problem-solving skills.

A number of scales have been proposed to measure self-directed learning as outlined by Litzinger et al [1], Saks and Leijen [2], Bullock [4], Swart [10] and Cadorin et al [16]. But, considering the above characteristics of engineering design and education, Williamson's self-rating scale of self-directed learning (SRSSDL) seems most appropriate to detect the skills required for pre- and in-service teachers as lifelong learners [17]. Williamson's scale consists of five subscales [10]:

1) *Awareness* - understanding factors that contribute to self-directed learning.
2) *Learning strategies* - strategies for self-directed learning.
3) *Learning activities* - activities linked to self-directed learning.
4) *Evaluation* - monitoring individual learning.
5) *Interpersonal skills* - skills needed to engage in self-directed learning.

STUDY CONTEXT

Technology and engineering education for pre-service teachers for primary school teaching in Slovenia is organised as follows: 15 hours of teacher-led instruction; 30 hours of practical work in schools (observation and teaching); and 30 hours of hands-on laboratory work. The content is as follows:

- introducing students to the world of design and technology using construction sets and active learning;
- machine elements, their specifications, design rules, joints, drives, and motion as part of toys and construction models;
- design-based work using technical puzzles and sets;
- methods for the development of work habits, skills and knowledge;
- planning, motivation, organisation and promotion of creative technical educational activities for use in schools;
- different working, processing techniques and engineering of paper materials, clay, artificial materials, wood, soft metals and composite materials together with the safe use of machining or working tools, equipment, devices and machines.

The following are the learning outcomes:

- understanding materials and engineering with the safe use of tools, machines and devices;
- being able to integrate technology and engineering subject matter for all levels of work in schools;
- reflecting on creative activities that affects children's cognitive development;
- to extend knowledge and skills with critical thinking, decision-making and heuristics students are given an open-ended challenge in which constraints (e.g. set of materials, time, functionality and range of use) are defined.

To fulfil the pilot-project requirements, the curriculum for pre-service teachers of technology and engineering was modified including:

- content (what we teach);
- process (how we teach);
- product (what we expect the students to do or show);
- learning environment (where we teach).

A special focus was on the need for pre-service teachers to identify what students know, how they learn and are able to do, to relate these to effective teaching. Self-directed learning is an essential skill to be acquired for the effective learning of technology and engineering. In this study, socio-constructivist physical and virtual learning spaces were designed for technology and engineering courses to facilitate self-directed learning within a higher education setting. The course supported a student-centred and self-directed approach through the innovative use of ICT.

The author developed a model where ICT was used for acquiring technological knowledge and metacognitive, inter- and intrapersonal skills, viz.:

- Communication portal: Web site and e-mails.
- *Moodle* classroom with learning material: interactive lectures, laboratory exercises, H5P (HTML5 package) test applications.
- Assessment and progress measurement: *Plickers* assessment tool with QR (quick response) code cards and smartphones.
- Technology literacy measurement: timely, in different phases of the teaching/learning; test items designed using the method developed by Avsec and Jamšek [18].
- Mobile learning: monitoring student practice in schools; Google forms adopted for mobile devices.
- Mobilisation of student prior knowledge: technical stories, posted on communication portal one day before the lectures; reverse engineering or flipped learning was very high; at least of 85% were engaged in this type of 3-5 minutes' learning activity to elicit prior knowledge.
- *Mentimeter* system: anonymised students' reflections, opinions, evaluation.
- 3D technologies: develop student's mental ability for 3D manipulation using *TinkerCad* cloud computing for modelling; models from biodegradable and bioactive thermoplastic polylactic acid were printed using XYZ da Vinci Mini Maker 3D printer.
- H5P tool: work with rich material to create, share and reuse interactive HTML5 content; also, a plugin for the *Moodle* learning management system was enabled.

The key digital competencies are:

- the use of ICT in solving technological problems;
- the creative use of digital technologies;
- ICT for identifying needs and technological responses;
- the production of enriched digital content;
- co-operation and interaction using digital technology;
- handling data and digital content.

The two research questions that drove the research were:

1. How can the use of ICT in a teacher education course provide pre-service teachers with an opportunity to engage in self-directed learning?
2. How does self-directed learning affect the engineering design ability of pre-service teachers?

RESEARCH METHODOLOGY

An experimental research design, with quantitative data, was used in this study in a real classroom context. In this study, the target sample consisted of pre-service primary education teachers aiming to teach technology and engineering. The sample included all undergraduate registered students in the second year of study over a two-year period at the University of Ljubljana. In the academic year 2016-2017, a sample of 38 students was used as a control group, while in the academic year 2017-2018, 57 students were used as an experimental group. These were enrolled in technology and engineering classes where innovative ICT-based approaches were used for teaching and learning. In total, an effective sample of n = 95 students were used for this study. Female students were a large majority of the sample (98%), while there were only two male students in the study (2%).

Instrumentation

The SRSSDL questionnaire was used to survey students' perception of their ability for self-directed learning. This scale features 60 items in five subscales [17]:

1) awareness - 12 items;
2) learning strategies - 12 items;

3) learning activities -12 items;
4) evaluation -12 items;
5) interpersonal skills -12 items.

Responses for each item were rated on a five-point Likert scale (5 = always, 4 = often, 3 = sometimes, 2 = seldom, 1 = never). The questionnaire provides a measure of the self-directed learning level according to the following criteria by Williamson [17]. The maximum score is 300 points. A range from 60 to 140 points represents a low level of self-directed learning; from 141 to 220 represents a moderate level of self-directed learning; from 221 to 300 represents a high level of self-directed learning.

The internal consistency measured by Cronbach's alpha coefficient was very high overall at 0.94. The *awareness* subscale was 0.76; the *learning strategies* subscale was 0.82; the *learning activities* subscale was 0.81; the *evaluation* subscale was 0.86; and the *interpersonal skills* subscale was 0.80. Therefore, SRSSDL was found to be a reliable and valid instrument, and appropriate to use in higher educational settings [16].

To assess creativity specific to engineering design, a modified test for creative engineering design assessment (CEDA) was used for pre- and post-testing [19]. The instrument consists of three design problems, each with five parts to assess an individual's ability to formulate and express design ideas through sketching, descriptions, identifying materials, identifying problems that the design solves and its potential users. Participants generate up to two designs per problem. Total time for this assessment was 30 minutes for three problems or about 10 minutes per problem. Measured dimensions of the assessment tool included both problem-solving and problem-finding abilities. Problem-solving is the ability to derive a solution to a problem or situation. Problem-finding is a skill often found in art, yet is also necessary in science, technology and engineering. Problem-finding is the ability to identify problems or be able to foresee potential problems that may occur, but have not yet occurred.

Along with the above abilities, the instrument also assessed constraint satisfaction, where students use shapes and materials within the parameters or constraints of a design. Moreover, both convergent thinking, where students provide one solution to a given problem, and divergent thinking, where students provide between two and four different solutions to each problem, was measured by this instrument. All of problem-finding, problem-solving, constraint satisfaction, divergent and convergent thinking are relevant to an engineer's creativity. Pre-service teachers were evaluated according to the following subscales [19]:

- Fluency: amount of ideas; number of responses (0-100).
- Flexibility: number of response categories defined as the variety of responses or number of category types (0-100).
- Originality: qualitative number assigned to each design and to the entire problem (0-10).
- Usefulness: qualitative number assigned to each design and to the entire problem (0-4).

The Cronbach's alpha coefficient value indicated that the instrument was highly reliable both for pre-test at 0.86 and post-test at 0.91. All Cronbach's alpha values for the subscales were greater than 0.80.

Procedure and Data Analysis

A paper and pencil method was used by instructors to distribute the survey and the test. Students participated in the study during classroom sessions throughout a study day. The CEDA test was administered as a pre-test at the beginning of the study years in October 2016 and 2017 and as a post-test at the end of the semester where technology and engineering subject matter ended in January 2017 and 2018. The SRSSDL test was used as a one-shot study after the completion of the technology and engineering teaching.

Data analysis was conducted using SPSS software. Descriptive analyses were conducted to present the students' basic information and the mean scores of the dependent variables. An analysis of variance (ANOVA) and multiple regression analysis were conducted to find and confirm significant relationships between the groups with an effect size calculated using the eta squared (η^{2}) statistic.

RESULTS AND DISCUSSION

Ninety-five pre-service teachers were involved in this study with an average age of 20.55 years. The participants were predominately female (93 out of 95, 98%). The test-retest reliability of the CEDA test as measured by the *intraclass correlation coefficient* was 0.76, which represents *good reliability* [19].

SRSSDL Scores

The average score obtained by the participants was 238.5 out of 300 with a standard deviation SD = 24.4 and range of 169-297. This represents a *high level* of self-directed learning ability. Some 25% of the sample obtained 221 points or less, while about 75% of the participants obtained 245.4 points or less. Stratifying the scores as suggested by Williamson [17], no participant was placed at the lowest level (60-140) and 21 (22%) of the participants were placed at the intermediate level (141-220), while the majority (74, 78%) were placed at the highest level. Figure 1 shows the student average scores on each subscale of SRSSDL.

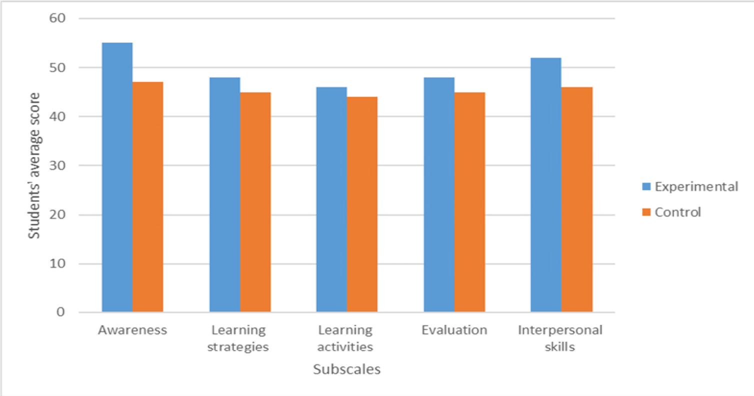

Figure 1: Students' self-directed learning scores on SRSSDL subscales for the experimental and control groups.

Tests of between-group differences in self-directed learning revealed significant differences ($p < 0.05$) for the subscale awareness ($\eta^2 = 0.15$), learning strategies ($\eta^2 = 0.81$), evaluation ($\eta^2 = 0.06$) and interpersonal skills ($\eta^2 = 0.17$). In general, scores from the survey are comparable with previous research in higher education settings [10][16]. Perhaps, a difference found between groups is a result of the post-test experiment.

Creative Design Assessment

To find within (effect over time) and between (group of students) subject effects a two-way ANOVA with repeated measures was used. The experimental group pre-test mean M = 88.71 (SD = 18.16), while post-test results were higher with M = 113.82 (SD = 17.53). The control group pre-test M = 84.87 (SD = 17.03), while the post-test M = 90.52 (SD = 21.17). The effect of teaching/learning technology on engineering design ability was found to be significant with a strong effect size ($\eta^2 = 0.37$). Moreover, calculating the difference, delta (Δ), between pre- and post-test mean scores, and using the engineering design score gain (Δ) as a dependent variable, ANOVA revealed that the experimental group score gain in the course, $M_\Delta = 25.11$ (SD = 19.12), while the control group score gain $M_\Delta = 5.65$ (SD = 20.39). This difference in engineering design gain is regarded as significant with a large $\eta^2 = 0.19$. The effect of the use of innovative approaches to teaching/learning of technology and engineering subject matter for pre-service teachers is shown in Figure 2.

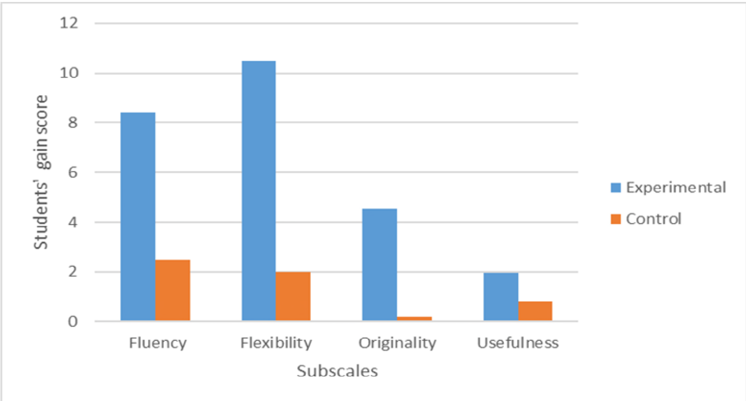

Figure 2: Pre-service teachers' engineering design gain (Δ) on CEDA subscales for experimental and control groups.

An innovative ICT-supported course brought significant gains, especially in flexibility of ideas, critical thinking, resource identification and in the originality of designed products. These skills revealed students proactively taking responsibility for their own learning. All of these skills and attributes developed on the course are characteristic of a highly self-directed learner.

Correlational Analysis

A multiple regression analysis was carried out, with the students' self-directed learning subscales as independent variables and student engineering design gain as the dependent variable. A linear relation was assumed between independent (predictor) and dependent (criterion) variables. It was found that scores on the subscale *evaluation* significantly ($p = 0.004$) predict engineering design gain with a beta weight, $\beta = 0.53$. This can be explained since *evaluation* relates to the ability to evaluate, to monitor, check, identify own weaknesses and strengths, and to find new learning challenges. These would point to a higher ability for engineering design. Moreover, results indicate that as the degree of complexity of a project increases, a designer's experience may boost ability in the design process. This confirms the findings of Nazidizajin et al [20].

Surprisingly, a negative predictor was found for engineering design gain. Students who scored higher in the *learning activities* subscale have significantly ($p = 0.021$) lower scores in engineering design gain ($\beta = -0.42$). Students with a high cognitive ability prepare themselves for learning in a very systematic and organised way. But innovation requires a distinctive approach requiring technological knowledge with *to-do* skills and a positive attitude towards technology and engineering [5]. This is a sign that innovation as practice-oriented needs more attention in education.

CONCLUSIONS

An effective model was developed to support self-directed learning in ICT-intensive learning environments. Pre-service teachers' responses to the incorporation of self-directed strategies have been positive. Research results indicate that the incorporation of self-directed learning-support strategies impacts positively on teaching and learning among pre-service education students. Moreover, design, as part of a core technology and engineering course might be developed through self-directed learning and advanced use of ICT.

The implication of these studies is that technology and engineering curricula must be modified to include multiple learning experiences and high-impact practices that challenge pre-service teachers to develop self-directed learning skills, if pre-service teachers are to improve on these critical skills.

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