THE EFFECT OF USING “LEARNING-BY-DOING” APPROACH ON STUDENTS’ MOTIVATION IN LEARNING DIGITAL ELECTRONICS

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ABSTRACT

First-year students from the Diploma in Telematics and Media Technology (DTMT) course in the School of Engineering at Nanyang Polytechnic, Singapore learn Digital Electronics through the “learning-by-doing” approach during their first semester at the polytechnic. They learn digital electronic circuits by designing and implementing a prototype of a practical digital security system. The students are also required to come up with innovative ideas of applying the digital security system in everyday life and showcase these ideas in an exhibition, which serves as an additional platform for students to develop their interpersonal skills. Students from the DTMT were found to be more motivated and interested in learning Digital Electronics, as compared to students from another diploma course where they learned Digital Electronics in the traditional way of attending lectures, tutorial classes and practical laboratory sessions. This paper shares our experiences in adopting the “learning-by-doing” approach in the teaching of Digital Electronics where instruction is designed to engage students in direct experiences that are tied to real world situations, and to develop students’ interpersonal skills. Key findings from the data collected through surveys and interviews are summarized in this paper to highlight the effect of the “learning-by-doing” approach on students’ motivation in learning.

KEYWORDS

Learning by Doing, Module Effectiveness, Motivation in Learning, Standards: 8

Note – In the context of Nanyang Polytechnic, the term ‘course’ refers to a ‘program’ while the term ‘module’ refers to a ‘course’. For example, *Diploma in Telematics and Media Technology* is a course; *Digital Electronics* is a module.

INTRODUCTION

Students from the Diploma in Telematics and Media Technology (DTMT) course in the School of Engineering (SEG) at Nanyang Polytechnic, Singapore learn the concepts and skills of Digital Electronics (DE) through the “learning-by-doing” approach which allows students to build their understanding of concepts through a process of inquiry and reflection.

The key objective of adopting this “learning-by-doing” approach in teaching first-year DTMT students on DE is to motivate them and increase their interest in the module. The “learning-by-doing" approach adopted in DTMT follows the experiential learning model promoted by the Experiential Learning Project Group (ELPG) from University of California Science, Technology and Environmental Literacy Workgroup. Experiential learning has been described as a pedagogy that motivates students ("Experiential learning defined", 2016), as it encompasses various motivational strategies identified by researchers (Ambrose et al., 2010).

There are several models that characterize the cyclical learning process of experiential learning, ranging from a one-step model to a six-step model (Neill, 2002). We adopted the three-step model by ELPG in our module design, which identifies the steps as "experience", "reflection", and "application" ("Why EL?", 2016). This three-step model is adapted from Kolb's four-step model (1984) of "concrete experience", "reflective observation", "abstract conceptualization" and "active experimentation". In the three-step model, a lecturer acts as a facilitator to provide challenges, encourage risk taking, correct errors, and provide context. Students, on the other hand, build experiences when they are involved in doing a task (the experience phase), share their observations and process the experiences by discussing and analyzing (the reflection phase), and deepen their understanding of the concept through applications (the application phase). In this cyclical learning process, students have the opportunity to try independently on their own and possibly fail. It is through this experience of failing that provides the most important learning opportunity for students, and it acts as stepping stones towards students' success in real life.

MODULE DESIGN

Based on the three-step model, the module design is summarized in Table 1. The first part of the instruction is designed to introduce to students the concepts of DE, teamwork, thinking and problem-solving skills. In the second part of the instruction, students work individually on his/her first project in building and developing a practical system that demonstrates the principles of DE circuits, and get themselves familiarised with the necessary tooling and experimentation skills.

In the final part of the instruction, students are assigned into groups to work on their second project where they are given the freedom to come up with different ideas of application prototypes for the DE circuit system they have developed in the second part of the instruction. The students are expected to apply the DE skills learnt in developing the innovative prototypes. In order to motivate the students further, a project exhibition cum voting competition is held at the end of the module, where visitors vote for their favourite prototype designs. The exhibition also gives students a platform to demonstrate their presentation skills.

The module design follows the three-step model of experiential learning closely. Firstly, students "experience" how to apply the DE concepts learnt in developing and building every single part of a security entry system through the individual project phase. They have opportunities to reflect upon their observations and problems while experimenting and solving problems arising from their mistakes. They are also encouraged to discuss and analyse issues faced with their lecturers and peers. The group project in the final part of the instruction allows the students to "apply" the knowledge and skills learnt in developing a real-life project prototype. The whole learning process aims to excite and motivate them to deepen their learning of DE concepts.

Table 1. Module Design

<table>
<tr><th colspan="2">60 Hours of Instruction – 4 hours per week over 15 weeks</th></tr>
<tr><td>Week 1 to 2</td><td>Topics to be covered in the first 2 hours:
Introduction to CDIO (~½ hour)
Teamwork (~½ hour)
Creative, Critical Thinking & Problem Solving Skills (~1 hour)
Topics to be covered in the next 6 hours:
DE concepts (Part 1)
Individual Project – Familiarisation with Tooling & Experimentation</td></tr>
<tr><td>Week 3 to 9</td><td>Topics to be covered:
DE concepts (Part 2)
Individual Project – Build security entry system part by part & perform functional test</td></tr>
<tr><td>Week 10 to 14</td><td>Group project
Brainstorm ideas for prototype
Source materials for prototype
Build prototype
Integrate the security entry system into prototype</td></tr>
<tr><td>Week 15</td><td>Project Presentation & Exhibition</td></tr>
</table>

This implementation contrasts the traditional way of learning DE in other courses, where theories and concepts of DE are learned through lecture and tutorial classes, and verified through practical laboratory sessions.

Individual Project – Security Entry System

The project is designed for the students to get familiar with DE components (such as basic logic gates, encoder, latch, comparator, etc.), DE circuit diagrams and concepts (such as Boolean Algebra, Karnaugh Map and combinational logic design), and prototyping tools. Students also learn experimentation skills through the process of building a security entry system (Figure 1). They are guided to prepare component layout diagram, solder and/or wire-wrap the components onto the prototyping board. Every student is required to understand each part of the circuits before they start to work on the circuit connections on the prototyping board. They are also expected to perform functional tests for their circuit board.

The project provides a platform for the students to understand the practical applications of their basic knowledge learnt about DE through first-hand experience. The students would most likely face some challenges in troubleshooting their mistakes made along the way. They would then be guided to solve the problems through their reflections upon self-discoveries and/or discussions with the lecturer or their peers. They also learn how to persevere through failures. After the completion of the individual project, every student is expected to share their learning experiences with the class. This process facilitates peer-learning in the class. Through this project, the students are able to build up their technical capabilities and gain confidence for the group project.

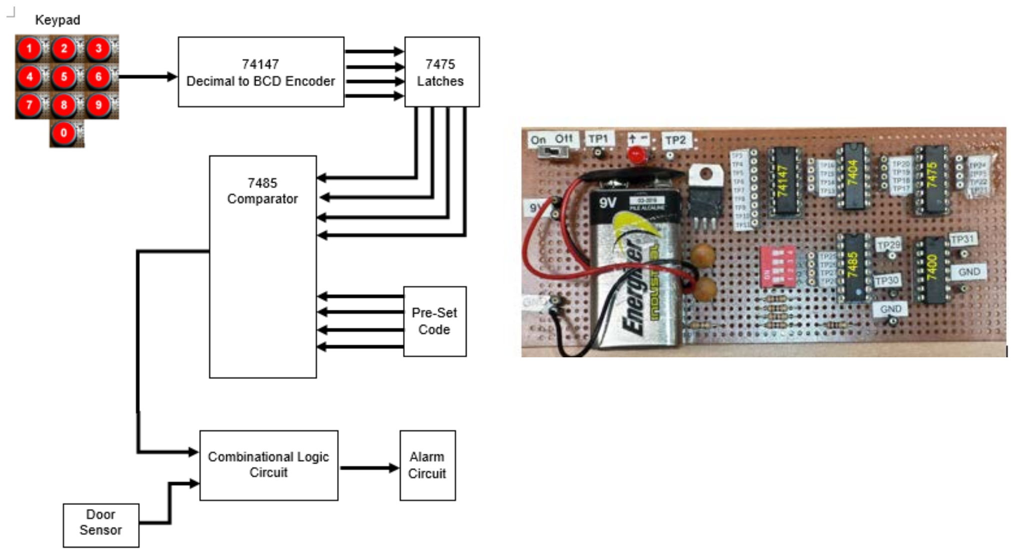

Figure 1. Security Entry System (Individual Project)

Group Project – Prototype Design

For the group project on prototype design, students are grouped into teams of two or three members each. The teams are given the freedom to come up with different ideas for the innovative prototype (examples are shown in Figure 2) they are tasked to design. All the prototypes are to incorporate the security entry system that the students have built. As it is a group project, members within a team are assigned different responsibilities, such as designing and building the prototype, sourcing materials for the prototype, and presenting their project. Though the students are expected to integrate the security entry system into their prototype designs, they are allowed to make changes to the connections if necessary, in order to fit the circuits properly into their prototypes. In this process of trying and fitting the wire connections into their prototypes, they are expected to learn through multiple failures. With the guidance and support provided by the lecturer, it is hoped that the experience of these failures motivates the students to learn and do more in order to complete a successful prototype.

Figure 2. Prototype Designs (Group Project)

In order to motivate and excite the students further, a voting competition is held at the end of the semester. The students are to invite their friends, lecturers and parents to visit the exhibition that showcases their prototypes. During the exhibition, the students pitch their ideas to win votes from the visitors. This whole learning experience intends to enhance students' teamwork, communication and presentation skills, and also allows them to practise problem-solving skills.

INITIAL FEEDBACK FROM STUDENTS AND FACULTY

At the end of the first semester of every academic year, a survey is conducted to gather feedback from the DTMT students on the module. The students are asked a series of questions that seek to validate the objectives and the delivery of the module.

Table 2. Results from Previous Surveys Conducted in 2013 and 2014

Do you agree?	**Students' Response**	
	2013 (20 Students)	**2014 (18 Students)**
1. The learning objectives of this module are clear.	100% agreed	100% agreed
2. The module is well organized.	100% agreed	100% agreed
3. The pace is just right.	100% agreed	94% agreed
4. The module stimulates my interest to learn more about DE and my engineering discipline.	100% agreed	100% agreed
5. The module is relevant to other modules in the same semester.	100% agreed	94% agreed
6. Feedback provided by lecturers is helpful and timely.	100% agreed	100% agreed
7. Grading criteria are clear and fair.	100% agreed	89% agreed
8. Overall, the module is worthwhile.	100% agreed	100% agreed

The results from the surveys (Table 2) conducted in 2013 and 2014 indicated that majority of the students agreed that the learning objectives were clear and found the module to be well organized and conducted with the right pace. They appreciated the relevance of this module to other modules they studied. Grading criteria of the module were also deemed clear and fair. These results reflected the success of the module delivery in incorporating strategies that help to increase the value students placed on the learning activities created for them, as well as strategies that strengthen students' expectancies. These strategies help to create an environment that supports motivation in learning (Ambrose et al., 2010).

Most students commented that they enjoyed the "learning-by-doing" approach. They also found the module helpful in developing their interest, and they wanted to learn more about DE and their engineering discipline. The students reflected that they liked the hands-on experience of developing projects in teams, which allowed them to learn more effectively through self-discoveries and to persevere through their failures.

More significantly, the lecturer also observed that these DTMT students were much more engaged and motivated to learn more about DE during the lessons, as compared to students studying similar module in other courses. The DTMT students were enthusiastic in completing their projects and were excited in participating in the project exhibition and competition.

INVESTIGATION ON STUDENT MOTIVATION

With the positive feedback received from students and lecturer, we wanted to conduct further study to measure the effects of the "learning-by-doing" approach on students' motivation in learning DE as compared to the traditional approach of conducting lectures, tutorials and labs. In this study, we used a mixed method to collect data for analysis. The Intrinsic Motivation Inventory (IMI) (2016) was used to collect quantitative data, and interview with selected students was conducted to collect qualitative data.

The IMI was developed by Ryan (1982) and his colleagues from the Rochester Motivation Research Group. It has been widely used in studies related to intrinsic motivation and self-regulation (Wang et al., 2011; Loukomies et al., 2013). The IMI comprises of seven subscales with 45 items. The seven subscales are interest/enjoyment, perceived competence, effort/importance, value/usefulness, pressure/tension, perceived choice, and relatedness. For every item, the students taking part in the survey have to indicate how true the statement is describing their experience while performing a given activity on a Likert scale from 1 (not true at all) to 7 (very true).

Table 3. Selected Subscales of IMI

1) Interest/Enjoyment	2) Perceived Competence	3) Effort/Importance
• I enjoyed doing this activity very much. • This activity was fun to do. • I thought this was a boring activity. (R) • This activity did not hold my attention at all. (R) • I would describe this activity as very interesting. • I thought this activity was quite enjoyable. • While I was doing this activity, I was thinking about how much I enjoyed it.	• I think I am pretty good at this activity. • I think I did pretty well at this activity, compared to other students. • After working at this activity for a while, I felt pretty competent. • I am satisfied with my performance at this task. • I was pretty skilled at this activity. • This was an activity that I couldn't do very well. (R)	• I put a lot of effort into this. • I didn't try very hard to do well at this activity. (R) • I tried very hard on this activity. • It was important to me to do well at this task. • I didn't put much energy into this. (R)
4) Value/Usefulness	**5) Pressure/Tension**	**6) Relatedness**
• I believe this activity could be of some value to me. • I think that doing this activity is useful for promoting my interest in learning engineering. • I think this is important to do because it shows me how to build, test and package a prototype of digital electronic project. • I would be willing to do this again because it has some value to me. • I think doing this activity could help me to sharpen my thinking and problem solving skills in group works and presentation. • I believe doing this activity could be beneficial to me. • I think this is an important activity.	• I did not feel nervous at all while doing this. (R) • I felt very tense while doing this activity. • I was very relaxed in doing these. (R) • I was anxious while working on this task. • I felt pressured while doing these.	• I felt really distant to my teammate. (R) • I really doubt that my teammate and I would ever be friends. (R) • I felt like I could really trust my teammate. • I'd like a chance to interact with my teammate more often. • I'd really prefer not to interact with my teammate in the future. (R) • I don't feel like I could really trust my teammate. (R) • It is likely that my teammate and I could become friends if we interacted a lot. • I feel close to my teammate.
Note: The items marked with (R) are negative statements. To calculate the item score, subtract the item response from 8.		

Of the seven subscales, six were determined to be relevant to our investigation. We exclude the subscale on perceived choice as all the learning tasks and activities were compulsory for all students taking the module. The six subscales with a short description on the dimension that they measure are listed below, and the questionnaire items are listed in Table 3:

1) Interest/Enjoyment – students who enjoy doing an activity are more motivated;
2) Perceived Competence – students who perceive themselves competent in doing an activity are more motivated;
3) Effort/Importance – the amount of effort a student puts in for an activity or the level of importance a student assigns to an activity is considered highly relevant to his/her level of motivation;
4) Value/Usefulness – an aspect that is related to one's internalization of an experience;
5) Pressure/Tension – students who experience pressure or tension in doing an activity are less motivated;
6) Relatedness – an aspect that is related to interpersonal interactions or friendship formation during an activity.

The items were randomized in their sequence before they were presented to the students in the form of a survey. The entire cohort of year-one DTMT students (20 students) took part in the survey at the end of the semester. At the same time, another 14 students having similar academic profiles as the 20 DTMT students were selected from the Diploma in Electronics, Computer and Communications Engineering (DECC) course to participate in the same survey. These 14 students from the DECC learned DE in the traditional way of Lecture-Tutorial-Practical delivery.

RESULTS

Quantitative Study

The results of the survey are summarized in Table 4. The effect size of each of the six IMI subscales between the two groups of students was then computed based on Cohen's d criteria ("Effect Size (ES)", 1996). The outcomes are shown in Table 5.

The results from this investigation using IMI indicate a significant difference in students' self-report of the interest/enjoyment subscale and the perceived competence subscale. There is evidence that DTMT students had higher interest and enjoyed learning DE through the "learning-by-doing" approach, as compared to students from the DECC who learned the subject in the traditional way. There is also evidence that students from the DTMT perceived themselves to be more competent in the DE as compared to students from the DECC. Furthermore, DTMT students appreciated the value or usefulness of the module more while experiencing less pressure or tension in class. These quantitative results reinforced the recognition from past surveys and observations that the "learning-by-doing" approach is effective in enhancing students' motivation in learning DE.

Though the results show only a small difference between DTMT students and DECC students on the relatedness subscale, the average rating of this subscale was the highest for DTMT students among the six subscales. This shows that they were experiencing supportive relations with their teammates while they were working on the group project. As for the results on the effort/importance subscale, the difference is insignificant. It was initially worried that the students might place less importance on this module, as it does not require the students to sit for formal examination at the end of the semester. Hence, the results were encouraging as they only indicated a trivial effect.

Table 4. Results of Survey Using IMI

IMI Subscales	DTMT Students (20)		DECC Students (14)	
	Average Rating	Standard Deviation	Average Rating	Standard Deviation
Interest/Enjoyment	***4.99***	***0.70***	***4.13***	***1.09***
Perceived Competence	***4.65***	***0.86***	***3.99***	***0.80***
Effort/Importance	***4.72***	***1.30***	***4.79***	***1.07***
Value/Usefulness	***5.22***	***0.73***	***4.58***	***1.07***
Pressure/Tension	***3.45***	***0.96***	***4.15***	***1.58***
Relatedness	***5.26***	***0.97***	***4.97***	***1.41***

Table 5. Effect Size Computations Based on Cohen's d Criteria[1]

IMI Subscales	Cohen's d	Effect Size
Interest/Enjoyment	0.94	Large
Perceived Competence	0.79	Large
Effort/Importance	-0.06	Very Small
Value/Usefulness	0.7	Medium
Pressure/Tension	-0.54	Medium
Relatedness	0.24	Small

Qualitative Study

Six DTMT students were selected for interviews. Through these interviews, their views on the "learning-by-doing" approach adopted in the module were further revealed. The group project on prototype design and the final project exhibition were mentioned by the interviewees as the most interesting part of the module. One student specifically pointed out that her interest in engineering actually improved after knowing the applications of digital circuits through the module. The interviewees also enjoyed working on project in teams, and reflected that they valued the usefulness of personal and interpersonal communication skills they practised through the group project discussion and presentation.

Though the interviewees appreciated the usefulness of technical troubleshooting skills they learned through the individual project, they also commented that the challenges they faced during the troubleshooting process had somewhat killed their interest in learning the subject to a certain degree. While the quantitative results show a reduction on the IMI subscale of pressure/tension in general for DTMT students, the interviewees reflected it was during this troubleshooting stage that they experienced the most pressure. The students' confidence level of their technical skills might have suffered from failures experienced during this troubleshooting stage, as they commented that they were more confident in their soft skills than in their technical skills.

[1] A Cohen's *d*=0.2 is considered a 'small' effect size, 0.5 represents a 'medium' effect size and 0.8 a 'large' effect size. A 'small' and 'large' effect size implies the difference between the two sample sizes is trivial and substantial respectively.

When the interviewees were asked if they preferred the “learning-by-doing” approach to the traditional way, it was interesting to note that the students with prior hands-on learning experience in the secondary school agreed that the approach adopted in the module was more effective for their learning, whereas those without prior hands-on learning experience in the secondary school opined that they might learn better through the traditional way.

Lastly, the interviewees also revealed that the personality of the lecturer played a key factor in how they placed importance to a module. It confirms our belief that the lecturer plays an important role in triggering the students’ interest in learning a module. This reaffirms the findings of research studies on how teacher personality would determine teacher-student interpersonal behaviour and its effect on student learning outcomes (Fisher et al., 1998).

CONCLUSIONS

The adoption of the “learning-by-doing” approach to teach DE to the first-year students has been a successful effort. The surveys and interviews conducted with the students affirm the effectiveness of this approach in enhancing the students’ motivation in learning DE, as compared to those students who learn DE in the traditional way. However, the sample size of this study was limited by the small cohort size of DTMT students. As revealed by the interviews with selected DTMT students, there are other factors that might impose limitations on this investigation, which include the proportion of students with prior hands-on learning experience in the comparison group, and the personality of the lecturer teaching the comparison group. Hence, moving forward, the study on the effect of this “learning-by-doing” approach on students’ motivation will be extended to a larger scale that covers more modules and courses in SEG.

With the encouraging results from this small-scale investigation with the DTMT, more lecturers are encouraged to adopt the “learning-by-doing” approach in their modules. Nonetheless, we acknowledge that there are some challenges in adopting this approach. As pointed out by the interviewees in this study, the lecturer would have to address the difference in the students’ prior knowledge. More learning activities are to be put in place to scaffold the students in learning the technical troubleshooting skills. Providing some early success opportunities would motivate the students in overcoming the setbacks that they are likely to face in the application phase of their experiential learning (Ambrose et al., 2010). Feedback from the students hence plays an important part in helping the lecturers to fine-tune the processes and learning activities to ensure that the implementation of the “learning-by-doing” is sustainable, and the students gain fruitful learning experience from this approach.

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