A framework to encourage the use of reflective practices by undergraduate engineering students in a design-based module

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Abstract*—Design-based learning is drawn from concepts relating to problem-based and project-based learning. Design-based learning is used in this paper to refer to the design and construction of an electronic hardware project by undergraduate engineering students. Students often experience difficulty with design principles regardless of the methods used to teach them. Many factors contribute to this struggle, including the selection of an appropriate project, the choice of and availability of components, the design platform used and financial constraints. The following research question, therefore arises, "What proposed framework may be used to help guide undergraduate engineering students to successfully complete a design-based learning module"? The purpose of this paper is to present a proposed framework that engineering students may consult regarding selecting an appropriate project and components for their electronic project that will lead to higher academic success. Data obtained from completed student projects in 2015 and 2016 form the basis for this framework that focuses on the number and type of components used together with the final grade awarded to the project. A quantitative research methodology is used as the relationship between the number and type of components used in the electronic projects are quantified and correlated to the final grade awarded to the project. A total of 74 student projects were analysed, and a correlation was drawn between 53 different criteria and their final grade. Students who used battery power, plug-in wires, and DC motors attained a higher grade than students who did not. The proposed framework has the potential of guiding future undergraduate engineering students in selecting more appropriate components for their electronic projects that will enhance its performance and lead to higher academic success.

Index Terms*—Practical work, student perceptions, entry level, theory, freshman*

I. Introduction

"Is there anyone so wise as to learn by the experience of others?". These words, by the French writer Voltaire, certainly relates to teaching design principles to undergraduate engineering students in design-based modules (DBL). These students need to be guided and encouraged to reflect on the quality of their work and also work done by preceding students. The value of reflective practice is broadly accepted in education [1] and is a mechanism to turn experience into learning [2]. However, encouraging students to reflect on their work by considering the work of previous students has the potential to further enhance their work and academic achievement [3]. This reflection may be encouraged by providing detailed theoretical frameworks to students.

A theoretical framework is a structure that supports the theory of a research project [4], and may be used by individuals to reflect on what has been accomplished within a specified field. It also contains the seed for research problems that is connected to a particular field that may be used to guide, develop and shape specific research [5]. In the same way that a theoretical framework guides a researcher in the identification and understanding of a problem, it is envisaged that a proposed framework will guide undergraduate engineering students in the selection of an appropriate project along with its associated components. The proposed framework is based on the assessment of previous student projects in a DBL module. It further presents the correlation between the components used and the final grade that was assigned to the students.

The purpose of this paper is thus to present a proposed framework that engineering students may consult regarding the selection of an appropriate project along with its associated components in order to achieve academic success. Firstly, some principles relating to learning are discussed where after the context of the study is presented. The design of the proposed framework is then explained, followed by the results, discussions, and conclusions.

II. Principles Relating to Learning

A. Framework

Researchers are aware of the importance of theoretical frameworks in education, learning, and research [6]. Clarkson pointed out that "models and frameworks are helpful for clarifying theories and abstract ideas or constructs [7]. However, to be useful in practice, a model or framework must apply to the conditions that it is trying to describe, analyse or predict" [8]. Theoretical frameworks form the foundation for many research projects and are, among others, used to develop questionnaires [9] and design protocols [10]. They may also be used to explain principles [11], such as design principles used in DBL modules as described in this paper.

B. *Reflective learning*

Reflective learning is a process for reflecting on experiences that enable learning [12]. It is not only limited to student learning but is also a well-used technique by academics [13]. Reflective learning is imperative in academic studies [14] and is a method that encourages students to reflect on or meditate on all available sources of knowledge [15]. Its main aim is furthering understanding of complex situations, developing personal abilities and enhancing experience [16]. Reflective learning has been fostered in the current digital world where a wealth of data on almost every topic exists [17]. In the context of this paper, students will be requested to reflect on a proposed framework based on the analysis of previous student projects. This has the potential to enhance their experience and understanding of complex principles within DBL modules.

C. *Design-based learning*

DBL is an effective approach to learning that is centered on problem-solving in combination with project-based learning [18]. In the context of this paper, DBL is used in two modules which involve the conceptual aspect of learning (this requires knowledge seeking and idea formation) and the material aspect of learning (this requires the creation of prototypes and products) [19]. DBL is a trend in Engineering and Architecture that increases the objectivity of the learning process, while stimulating team and interdisciplinary work [20]. The advantages of DBL include providing a relevant opportunity for student learning, increasing student motivation and engagement [18], developing higher-order cognitive skills [21], promoting active learning [22], stimulating collaboration and cooperative learning and also fostering personal and interpersonal traits and creativity [23, 24].

III. CONTEXT OF THE STUDY

The Department of Electrical, Electronic and Computer Engineering at the Central University of Technology offers courses in electronic engineering, power engineering, and computer systems engineering. These courses deal with the study and application of electricity, electronics, electrostatics and electromagnetism which covers a range of sub-studies including power electronics, control systems, signal processing and telecommunications and more [25]

Engineering students may enroll for Higher Certificates, National Diplomas or B.Tech degrees, depending on their previous qualification. The National Diploma requires engineering students to complete a total of 360 credits (3600 national hours), which equates to around 20 modules, each with a credit value of 12. Also, there is a compulsory Work Integrated Learning module that has a credit value of 120. The National Diploma programs include both theoretical and practical instruction where students can demonstrate vital graduate attributes [26], including problem-solving using DBL. Two of the modules in the National Diploma involve DBL (called Projects II and Design Project III) where engineering students need to design and develop a working electronic project [27]

Table I indicates the structure of the practical part of the curriculum for Projects II and Design Project III. The learning outcomes include drafting a project proposal, writing progress reports, doing a project presentation, preparing the final report and presenting the final completed electronic project. Pedagogical methods used include consultations, classroom lectures, videos and a learning management system (LMS called Blackboard) where the progress reports are submitted. Constructive alignment exists between the learning outcomes and assessment methods, while the course content is drawn from journal articles, conference papers, e-books and the Internet.

TABLE I: STRUCTURE OF THE PRACTICAL PART OF THE CURRICULUM FOR PROJECTS II AND DESIGN PROJECT III

Learning outcomes **Students must be able to:**	**Assessment tools**	**Pedagogical methods**	**Syllabus**	**Content**
Compile and write a proposal for selected project	Evaluation on Blackboard using a rubric	Project consultations Demonstration of Arduino hardware and software (computer-based learning) Lectures Videos Oral presentation Learning management system	Project Proposal	Journal articles Conference papers E-Books Web pages
Compile and write a progress report for project	Evaluation on Blackboard using a rubric		Progress report	
Prepare and give presentation on project	Evaluation of an oral presentation by the student using a rubric		Presentation	
Compile and write the final report	Evaluation of a hard copy of the project documentation using a rubric		Documentation	
Design and construction of Arduino based project	Evaluation of completed project using a guideline		Complete electronic project	

A. Projects II and Design Project III assessment

Continuous assessment is used in both modules which are usually completed within a 14-week period. Both formative and summative assessments are used to cover the syllabus, as listed in Table I.

The project proposal contributes 10% to the final grade of the students. The project proposal is submitted via the institutional LMS approximately three weeks after the start of the semester. In the project proposal, the student identifies the project and answers a set of structured questions about the proposed project. These questions are set in a way that gives the lecturer an idea of the complexity and feasibility of the project. Students may hand in more than one proposal, but must obtain a minimum of 50% for one of the proposals before the stipulated deadline communicated to them in their study guides. The proposal must be approved by the lecturer before the student can continue with the proposed project.

There are also two opportunities for students to hand in a progress report on the LMS. The progress report consists of a section where the student submits a PDF file as proof of the progress of his/her project. This proof includes photographs that indicate the progress made, which is usually obtained by using student cell phones. Screenshots of their schematics, their PCB designs and any other relevant information about the progress of their project is included. In the second progress report, students will include a link to a You Tube video that they have uploaded that shows the actual working of their project on a breadboard. There is also a set of questions that are answered with every progress report. The questions are the same for both progress reports, with significance differences relating to the time left in the semester. For example, a question regarding the percentage of progress with the PCB will count 2% at the beginning of the semester, but 10% towards the end of the semester. Projects II and Design Projects III are continuous evaluation modules. Table II lists the different assessments that are done during the semester, together with the type and percentage in relation to the final grade. The two progress reports (formative in nature) for the module Projects II contributes 10% to the final grade and for Design Project III it contributes 20%. A theory test is written in Projects II, as there is a small theory section in the syllabus.

The oral presentation is a critical evaluation which requires students to present their projects to the rest of the class. Students are expected to explain the design by using a block diagram for the chosen hardware and a flow chart for the software. The oral presentation contributes 10% to the final grade for both the modules (See Table II). Finally, students submit a completed project and report for evaluation.

IV. Method of Framework Design

The proposed framework is derived from quantitative data obtained from analysing the electronic projects and results for students registered for Projects II and Design Project III (n=74) during 2015 and 2016. The projects were analysed regarding 53 components or variables that were used and are correlated to the final grade that was awarded. This correlation value is obtained by correlating each component (represented by a 1 or 0, depending on whether the student used it or not) to the final grades awarded to the students.

Many of the components are not used in all the projects. For example, the Infrared Sensor was used by 26% of the students, while the Arduino UNO were used by 85% of the students. Components that were present in more than 33% of the projects were therefore considered for the proposed framework.

Because the final grade is a continuous variable and the project related components are dichotomous variables, a point-biserial correlation was used. A point-biserial correlation is used to measure the strength and direction of the association that exists between one continuous variable and one dichotomous variable [28]. It is a special case of the Pearson's product-moment correlation, which is applied when you have two continuous variables, whereas in this case one of the variables is measured on a dichotomous scale [29]. The correlation was done between the different variables and the final grade awarded to the student at the end of the semester. Results are presented in the following section.

TABLE II: EVALUATION AND WEIGHTINGS OF THE MODULES PROJECTS II AND DESIGN PROJECT III

Evaluation	Type of assessment	Projects II	Design Project III
Proposal	Formative	10	10
Progress report 1	Formative	5	10
Theory test (Projects II)	Formative	10	
Progress report 2	Formative	5	10
Oral presentation	Formative	10	10
Documentation	Summative	6	
Article	Summative		6
Software design	Summative	6	6
Schematic + PCB	Summative	6	6
Construction	Summative	6	6
Wiring	Summative	6	6
PCB	Summative	6	6
Working	Summative	6	6
Demonstration	Summative	6	6
Hardware design	Summative	6	6
Level of Project	Summative	6	6
Total		100%	100%

V. Results

Fig. 1 represents the correlation between evaluations that were done during the semesters in 2015 and 2016 and the final grade allocated to the student for the project. For instance "Hardware design" was one of the evaluations that were done during the semester and it has a correlation coefficient of 0.84 when correlated with the final grade, where "Progress Report 2" has a coefficient of 0.49 when correlated to the final grade (see Fig. 1).

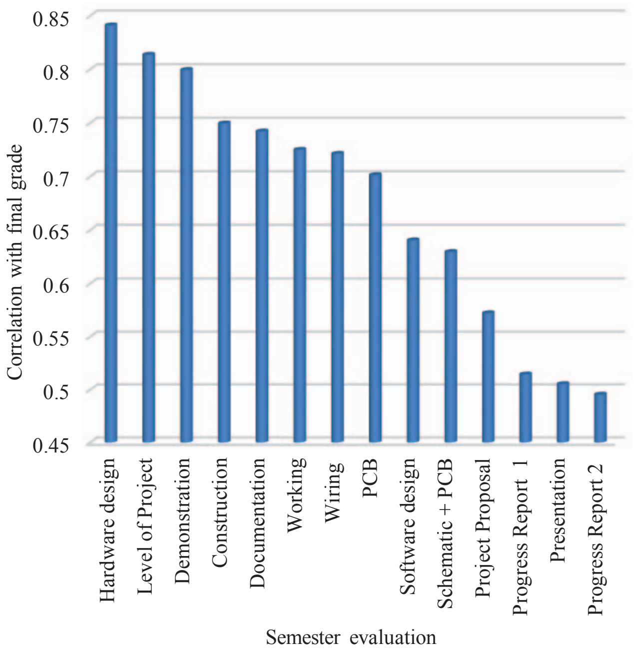

Fig. 1. Correlation between semester evaluations and final grades of student projects (2015 and 2016)

Fig. 2 highlights the correlation between 18 different project variables and the final grade awarded to the student for the project at the end of the semester. The variables in Fig. 2 are sorted from the lowest correlation to the highest correlation with the final grade. For instance, projects with a cardboard enclosure had the lowest correlation coefficient (-0.2) and projects that used only a battery as the power source had the highest correlation coefficient (0.26) with the final grade.

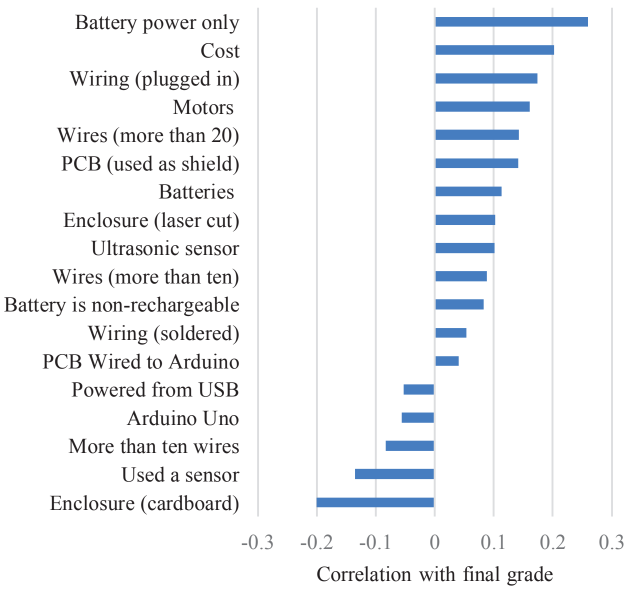

Fig. 2. Correlation between project components and final grades (2015 and 2016)

VI. Discussion

The aim of the proposed framework is to help future students make informed decisions regarding the choice of projects and components for the DBL modules Projects II and Design Project III. Fig. 1 illustrated the relationship between evaluations that were done during the semester and the final grade of the student. The evaluation of the hardware design component has a strong correlation with the final grade ($r = 0.841$). This suggests that future students need to pay special attention to the design of the hardware, as it has the greatest bearing on the final grade. Furthermore, the appropriate level of the selected project ($r = 0.813$) and the demonstration of the project ($r = 0.799$) is also shown to be critical for academic success in this module. Other correlations (higher than 0.7) were found for the PCB, wiring, working, documentation and construction of the project. It is noteworthy that a low correlation exists between evaluations that were done early in the semester (e.g. project proposal and progress reports) while higher correlations exist for the assessments done at the end of the semester (e.g. hardware and construction). This may be an indication that students grow in experience and acquire new skills as the semester progresses, as the weightings between these different evaluations remain similar (see Table II). Fig. 2 highlights the correlation between 18 different project components and the final grade awarded to the students for the projects at the end of the semester. Of the original 53 components, only 18 are presented as these were present in more than 33% of the 74 electronic projects that were analysed. Projects with cardboard enclosures had the lowest correlation coefficient (-0.2) while projects that used only a battery as the power source had the highest correlation coefficient (0.26) with the final grade. Cardboard has the advantage of being much less expensive than wood but suffers from the drawbacks that it is not as visually aesthetically pleasing as wood or hardboard and is also not as structurally firm [30]. In most applications, direct power from the USB is preferable. However, in some applications using a battery as the power source could be more preferable, especially when the application is frequently moved or when power cords could present a hazard [31]. In this case, the electronic projects frequently involve robotics, where an automated vehicle is designed that will require mobility and autonomy. These correlations suggest that projects with a cardboard enclosure have a smaller chance of academic success, while projects with a battery power source have a greater chance of academic success.

VII. Conclusions

The purpose of this paper was to present a proposed framework that engineering students may consult regarding selecting an appropriate project and components for their electronic project that will lead to higher academic success. The framework was developed by analysing 74 electronic projects from 2015 and 2016 and correlating 53 components or variables to the final grades awarded to the students. Only18 components were presented as they were present in more than 33% of the 74 electronic projects. Collecting data over a longer period of time with more projects can verify the results and strengthen the study.

Students who used battery power, spent more money on their project, used plug-in wires and DC motors attained a higher grade than students who did not use them. This proposed framework may provide guidance to future undergraduate engineering students in DBL modules to make informed decisions regarding the choice of their project and components. This guidance may encourage students to put forth their best, resulting in academic success. Furthermore, the proposed framework can assist academics to provide better guidance to students in the early stages of their project concerning the selection of an appropriate electronic project and its associated components. In so doing, both academics and students will be able to learn from the experiences of others, which is a wise course of action to follow.

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