

Arduino – Enabling engineering students to obtain academic success in a design-based module

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Abstract—A key graduate attribute for engineering students is the design and development of solutions for real-life problems. Enabling students to grasp engineering design principles often proves challenging, especially within the African context. The purpose of this paper is to highlight how the introduction of the Arduino microprocessor into a design-based module for undergraduate students has yielded outstanding results in this regard. Up until the end of 2014, students could choose their own microprocessor platform for designing electronic circuits required for specific applications. However, this led to several challenges, including the unavailability of components and the high costs of the microprocessors. Introducing the Arduino microprocessor as the preferred option in 2015 overcame many of these challenges, while at the same time leading to an improvement in the academic achievement of the registered students. A case study was used in this research along with descriptive statistics of the collected data. This data highlights that more than 90% of the students successfully completed this design-based module, while 70% felt that it really helped them to better understand the theoretical knowledge. This microprocessor has been recommended for future use in additional modules as it yielded positive results in 2015.

Keywords—*design-based learning; project-based learning; microprocessors; graduate attributes*

I. INTRODUCTION

“Technology is nothing. What's important is that you have faith in people, that they're basically good and smart, and if you give them tools, they'll do wonderful things with them.” [1]. These words, by Steve Jobs, highlight the importance of believing in the potential of people, including students in higher education. If given the appropriate training, they may reach their full potential, thereby demonstrating key graduate attributes such as the design and development of solutions for real-life problems. This attribute forms part of 12 graduate attributes stipulated by the International Engineering Alliance [2] and refers to student's ability to design solutions for broadly defined engineering problems that often require the use of the right technical equipment. Accreditation bodies, such as the Accreditation Board for Engineering and Technology (ABET), Engineers Australia (EA), as well as the European Accreditation of Engineering Programs (EUR-ACE), all specify that design is an essential graduate attribute for an engineering program [3].

However, Beckman and Barry [4] describe how students struggle with design principles regardless of the process used to teach them. Many factors contribute to this struggle, including the selection of an appropriate project [5], the design platform used in the project [6], non-availability of components [7] and financial constraints [8]. However, the effective use of design-based learning (DBL) has been reported to assist students in grasping fundamental design principles. DBL is centred on problem solving that is adopted from a combination of problem-based and project-based learning [9]. DBL in engineering education focuses explicitly on the design and/or construction of a final project that is either physical or computer based [10]. DBL is not a new concept in engineering education and many researchers have reported on it over the years. Research points to the positive effect of DBL on increasing student motivation and engagement, promoting active learning, promoting collaboration and cooperative learning, and fostering creativity [11].

As a result of the widespread use of DBL, it is difficult to define it precisely [12]. In DBL pedagogy, the student actively participates in the development and creation of the project, learning actively instead of passively. The student gains knowledge and skills that will come in handy later, through interactive discussions, group work, solving unexpected problems and constant design. The student develops a much broader level of knowledge and understanding, being better prepared for the world of engineering outside the classroom. [3].

The following research question therefore arises: “Can the Arduino microprocessor be successfully used for DBL in a design-based module to enable students to grasp fundamental design principles?”. The purpose of this paper is to illustrate how the Arduino technology is used in two design-based modules, termed Projects II and Design Project III, and how undergraduate engineering students have benefited from its use. This was done in an undergraduate course in electrical engineering offered at the Central University of Technology, Free State (CUT) in South Africa. Firstly, the use of Arduino in engineering education will be substantiated followed by the context of the study. The research methodology follows along with the results in tables and graphs. Key discussions follow with succulent conclusions.

II. ARDUINO IN ENGINEERING EDUCATION

Arduino was designed in Italy in 2005 to teach Interaction Design, a design discipline that puts prototyping at the centre of its methodology [13]. Some of the educational institutions where the Arduino is used include, MIT, Parsons School of Design, the University of California Irvine, Malmö University in Sweden, Keio University in Japan, the Taipei National University of the Arts in Taiwan, and many more [14].

The Arduino community consists of engineers and scientists as well as people from all walks of life, like artists, DIY hobbyists, students from engineering and non-engineering fields [15]. This large community uses the Arduino platform for effectively monitoring and controlling specific variables within a given environment. The concept of sharing designs on the web gives this community access to a broad knowledge base [15].

The Arduino platform is an open-source platform where the software and hardware is extremely accessible and very adaptable. The system offers a variety of digital and analogue inputs and outputs, serial interface and PWM outputs. It is easy to change and to update the programme as it connects to a PC via USB and communicates using standard serial protocol. The software is free and the hardware is inexpensive and easily available to students. Further advantages include:

- The IDE is freely available for Windows, Linux, and Mac.
- It is easy to change and update the programme as it connects to a PC via USB and communicates using standard serial protocol.
- It is part of a large online community with many references, example source codes and libraries.
- It is flexible and offers a variety of digital and analogue inputs/outputs, serial interface and PWM outputs.
- It is an inexpensive microcontroller.

On the other hand, there may be certain challenges in using the Arduino as an educational tool. Is it low level enough to be used by undergraduate engineering students who have never been exposed to DBL before? Is it possible for the lecturer to differentiate between the students own work and possible copied work from the Internet? These questions require debate. However, what is certain is that students using this platform will be exposed to a large number of design concepts [15] which they will have to demonstrate in their design.

The rise in popularity of the Arduino microprocessor on the Internet can be deduced from Fig.1, which presents results from Google regarding the word "Arduino". Data was obtained using Google trends, where the scores are based on the absolute search volume for a term, relative to the number of searches received by Google [16].

III. CONTEXT OF THE STUDY

The Department for Electrical, Electronic and Computer Engineering forms part of the Faculty for Engineering and Information Technology at CUT. The Department 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 [17].

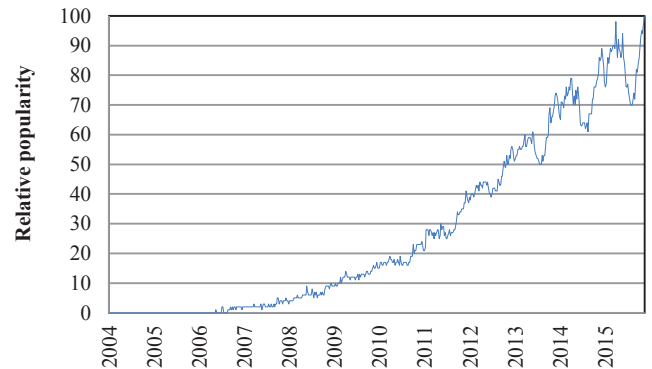


Fig.1. Relative popularity of Arduino over time on Google Trends

Engineering students may complete Higher Certificates, National Diplomas or B.Tech. degrees in electrical engineering, depending on the 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, along with their Work Integrated Learning modules which have a credit value of 120. The National Diploma programmes include both theoretical and practical instruction where students can demonstrate vital graduate attributes [18], including problem solving using DBL. Projects II and Design project III are two modules in the National Diploma where engineering students need to design a working electronic project.

The structure of the practical part of the curriculum for Projects II and Design Project III is indicated in Table 1, where the only difference is the level of the proposed project. The learning outcomes for the practical part include compiling a project proposal, writing progress reports, doing a project presentation, writing the final report and presenting the final completed electronic project. The pedagogical methods used in the presentation of the theory include personal one-on-one sessions, class presentations, videos and the learning management system (LMS). The syllabus is in line with the learning outcomes and assessment methods, while the course content is drawn from journal articles, conference papers, e-books and the Internet.

Traditionally, students could choose the design platform that they wanted to use in Projects II and Design Project III. Platforms that were used in the past included the PIC microcontrollers, non-microcontroller based projects (analog and digital), Raspberry Pi, Arduino and a combination of mentioned platforms. However, in 2015, after consulting with academics and industry, and considering all the advantages, it was decided to use the Arduino microcontroller as the design platform.

A. Evaluation of Projects II and Design Project III

Both the modules Projects II and Design Project III are continuous evaluation modules. Evaluation is done throughout the semester, with a final evaluation at the end of the semester when the final projects and documentation are handed in. Table 2 indicates the different sections that are evaluated as well as the significance of the evaluation.

The first grade awarded is for the project proposal that contributes 10% to the final grade for the modules. The project

proposal is submitted via the institutional LMS about 3 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.

TABLE 1: STRUCTURE OF THE PRACTICAL PART OF THE CURRICULUM FOR PROJECT II, AND DESIGN PROJECT III

Learning outcomes The student must be able to	Assessment	Pedagogical methods	Syllabus	Content
Compile and write a proposal for selected project	Evaluation on Blackboard	Project consultation	Project Proposal	Journal articles
Compile and write a progress report for project	Evaluation on Blackboard	Introduction of Arduino board and software (computer-based learning)	Progress report	Conference papers
Prepare and give presentation on project	Evaluation of oral presentation of student		Lectures	Presentation
Compile and write the final report	Evaluation of hard copy of project documentation	Videos	Documentation	Web pages
Design and construction of Arduino based project	Evaluation of completed project	Learning management system	Design and construction of complete project	

TABLE 2: EVALUATION AND WEIGHTINGS OF THE MODULES PROJECTS II AND DESIGN PROJECT III

Evaluation	Projects II	Design Project III
Proposal	10	10
Progress report 1	5	10
Theory test (Projects II)	10	
Progress report 2	5	10
Presentations	10	10
Documentation	6	
Article		6
Evidence of students own design in software	6	6
Schematic + PCB in article	6	6
Construction	6	6
Wiring	6	6
PCB	6	6
Working	6	6
Demonstration	6	6
Evidence of students own design in hardware	6	6
Level of Project	6	6
Total	100%	100%

There are also two opportunities for students to hand in a progress report, again 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. There is also a set of questions that are answered with every progress report. The questions are the same for both progress reports, with the significance adapted based on 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. A theory test is also written as there is a small section of theory in the syllabus of Projects II.

The presentation is an important evaluation, where the student has the opportunity to present his/her project to the rest of the class. The student is expected to explain the design by using a block diagram for the chosen hardware and a flow chart for the software. The student is also required to bring along everything that has been done in the project so far. A demonstration is not required, but the incomplete project must be presented during the presentation.

In the past, where students used other platforms rather than Arduino, they struggled with the connection and programming of intelligent LCD-type displays, among others. However, this is not the case when the Arduino platform is used. Students successfully make use of more complex systems such as Bluetooth, motor controllers, GSM modules and much more.

The ease with which more complex systems can be integrated with Arduino empowers students to be more creative in the design of their projects.

B. Examples of completed projects

Figures 2 and 3 are photographs of two completed student projects. The project in Figure 2 is a distance meter, where the distance from the ultrasonic sensor to a solid object is indicated on the LCD. Depending on the distance measured, between one and three LED lights are switched on. As soon as an object comes closer than a predetermined distance to the sensor, the buzzer is activated. In the figure, the PCB that the student designed as well as the ultrasonic sensor can be seen. The student must also provide a copy of the software which was written for this application.

The student project in Figure 3 is an obstacle avoidance robot. This type of project is very popular and students design many variations of it. The robot can work in two ways, namely obstacle avoidance and Bluetooth control. The robot will move forward until it is within a pre-programmed distance of a solid object, stop and move the ultrasonic sensor left and right with the help of a servo. Distance measurements on the right and left are compared and the robot will then retreat in the direction where there is no solid object in the way.

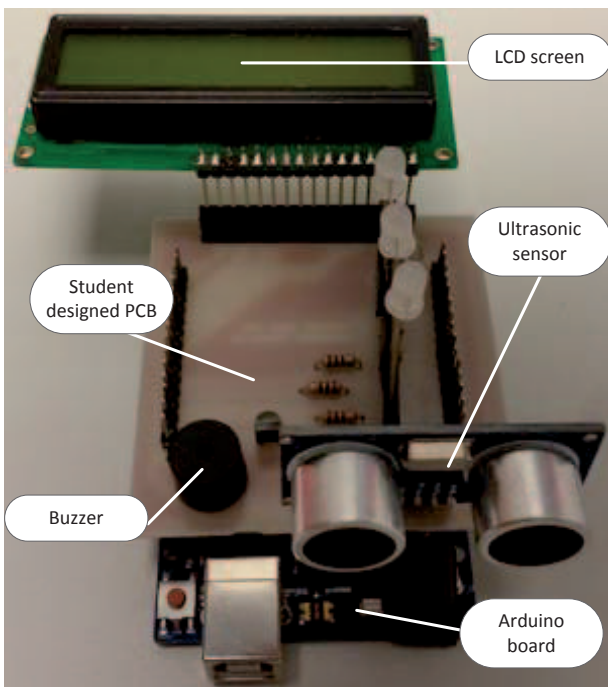


Fig. 2. Ultrasonic distance measurement with LED and LCD indicators

In the second configuration (of Figure 3), the Bluetooth module is used to move the robot using an app on the student's cell phone. The robot can be controlled by pressing left, right, forward or backward on the phone's touch screen. The ultrasonic sensor and Bluetooth module are popular components with the students. A motor controlled shield can also be seen in the figure, which includes space for a GSM module, radio frequency identification (RFID) system, transmitter and receiver systems, etc. Examples exist on the Internet to program these various shields. These shields help

students to progress much quicker from lower level systems to much more complex ones.

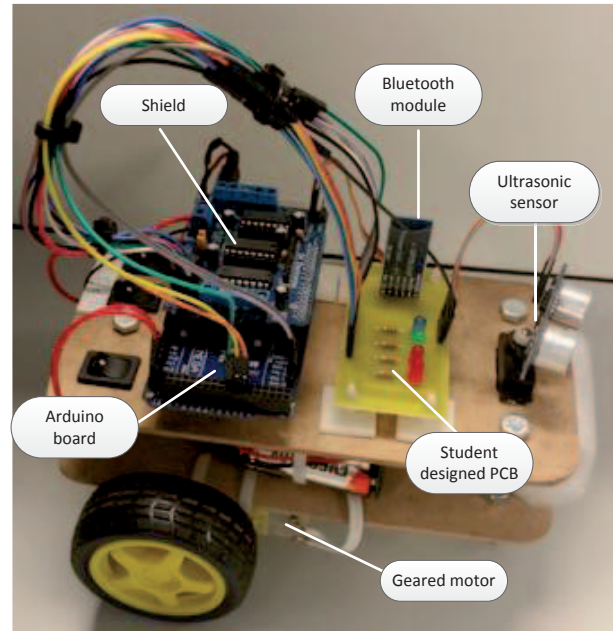


Fig. 3. Obstacle avoidance robot (Student project)

IV. RESEARCH METHODOLOGY

A case study was used in this research along with quantitative and qualitative data. The quantitative data of student perspectives on the use of the Arduino technology is presented using descriptive statistics. Descriptive statistics occur where a specific situation is studied to see if it gives rise to any general theories [19]. The specific situation was the incorporation of Arduino microprocessors, during 2015, into two design-based modules, termed Projects II and Design Project III. The target population was restricted to all students enrolled for these modules during the first semester of 2015, therefore requiring no sampling technique. To ensure a successful and sustainable integration of this new platform, it required regular feedback from students about their views of the learning experience and its associated outcomes [20]. Feedback was thus sought at the start and the end of the module. The final grades awarded to these students are also presented, and compared to previous semesters when the Arduino platform was not used, as discussed in the context section of this paper.

At the end of the course, additional student perspectives were obtained by means of an electronic response system and the institutions LMS. Quantitative data was gathered using a 4-point Likert-Scale (Strongly Agree to Strongly Disagree) and then converted into a number of bar graphs. Qualitative data was gathered on the LMS which sought to obtain student personal comments on the use of the Arduino microprocessor. These results were divided into a number of thematic themes. Student perspectives can be used to evaluate teaching innovations that prompt student achievement of course learning outcomes [21]. The questions were based on previous research relating to student perceptions of work done in an engineering laboratory [22, 23].

V. RESULTS

64 students enrolled for Projects II and Design Project III during the first semester of 2015 ($n = 64$). 68% were male with 32% female. 79% were between 20 and 24 years of age with 17% between 25 and 29 years. The survey indicated a total of 8 different home languages, with the significant ones being Sesotho (27%), Tswana (23%), Afrikaans (15%) and English (10%). At the start of the module, 66% of the students indicated that this was their first encounter with microprocessors. Students that have worked with microprocessors before (being 33% of the total) indicated that they had worked with the Arduino (20%) and with the PIC (9%) microprocessors.

Students were asked which sensors were they previously exposed too, before starting with this module. The results (shown in Figure 4) reveal that these students have prior experience in working with temperature (32%) and ultrasonic (9%) sensors. These percentages climbed dramatically at the end of the module, as more students had engaged with temperature (28%), humidity (2%), pressure (4%), magnetic (3%), compass (4%) and ultrasonic (46%) sensors.

Figure 5 presents student perspectives on the usefulness of the module itself. More than 90% of the students indicated that

they would encourage other students to take the module while 93% revealed that it was indeed a valuable learning experience for them. At the beginning of the semester, each student was given an Arduino Uno board to use, and hand in again at the end of the semester. Mixed results were obtained when students were asked if this board helped them to get started with the project!

Figure 6 presents perspectives on whether students felt that the Arduino was too difficult to work with. Less than 50% of the students felt that it was not easy for them to get started with the Arduino board, while more than 50% felt that it was not difficult to find information and examples on the Internet about the Arduino board. 91% of the students felt that their interaction with the Arduino helped them to better understand the theory.

Students were requested to evaluate the module at the end of the semester. Their perspectives were obtained using the institutional LMS, where seven themes were identified (similar comments by two or more students constitutes a theme). Table 3 indicates these different themes as well as the percentage of students who mentioned something relating to the theme.

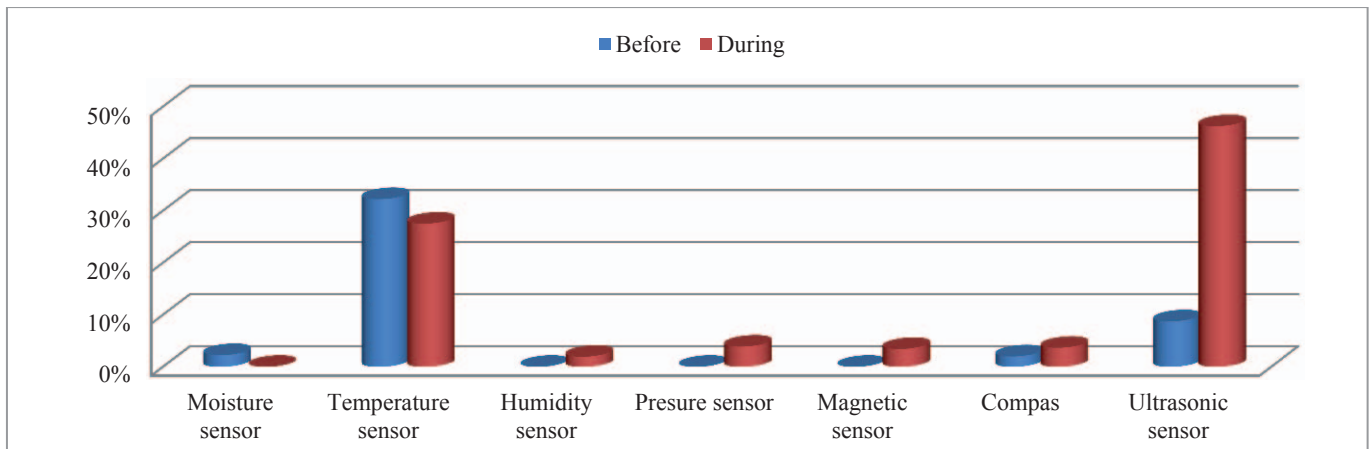


Fig. 4. Sensors used before and during the semester

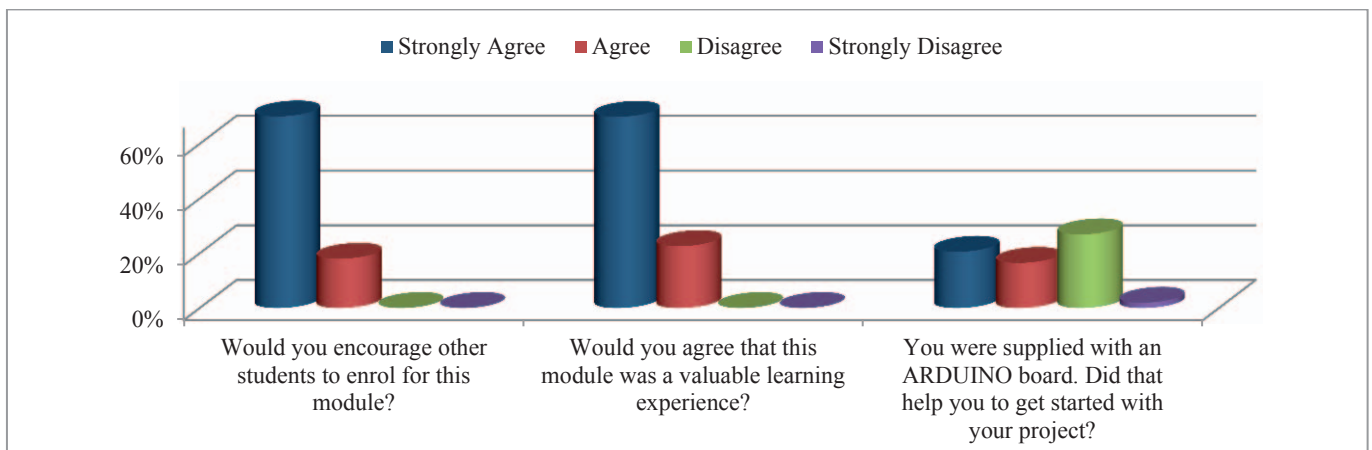


Fig. 5. Student perceptions on Projects modules

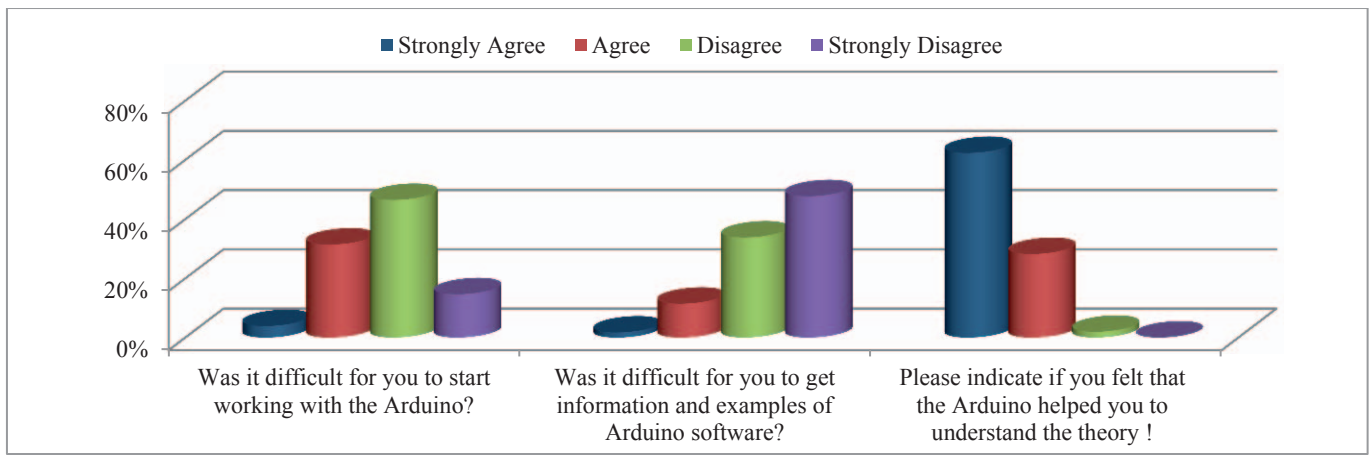


Fig. 6. Student perceptions on Projects modules

62% of the student comments were related to the theme that the module was a “good learning experience” (see Table 3). 36% mentioned that it was interesting, fun or enjoyable. A total of 70% of the students indicated in their comments that the module helped them to better understand the theory. Improved programming skills was reported by 36 % of the students and 26% reported on improved problem solving skills. 64% reported better design skills.

Figure 7 shows the final pass rates for the two modules since 2014. The pass rate is indicative of students who successfully completed the module by achieving a final grade of 50% or more. The pass rate for Projects II climbed dramatically from 61% in 2014 (Arduino platform was NOT used by all the students) to 92% in 2015 (Arduino platform used by ALL the students). A similar trend is observed for Design Project III (66% in 2014 to 93% in 2015).

TABLE 3 THEMATIC THEMES DERIVED FROM STUDENT COMMENTS

Thematic themes	Percentage of relating comments	Example of a student comment (Unedited)
Good learning experience	62%	In this module my learning experience it's very good.
Interesting, fun and enjoyable	36%	Honest opinion, it has been one of the most enjoyable experiences I have ever gained up to so far in life. It was very interesting and fun learning new things and also working with the Arduino
Helped to understand theory	70%	I have learned so much during this semester and I have also learned how to write the code of an LCD, ultrasonic, buzzer and servo motor as these components I have mentioned are the ones I have used.
Improved programming skills	36%	I believe I have learned allot. It was my first time programming and using an Arduino board so it was quite an experience for me.
Improved problem solving skills	26%	I learnt how to do solve electronic problems on my own in the simplest way.
Improved design skills	64%	I am now able to design my own project using the Arduino microcontroller

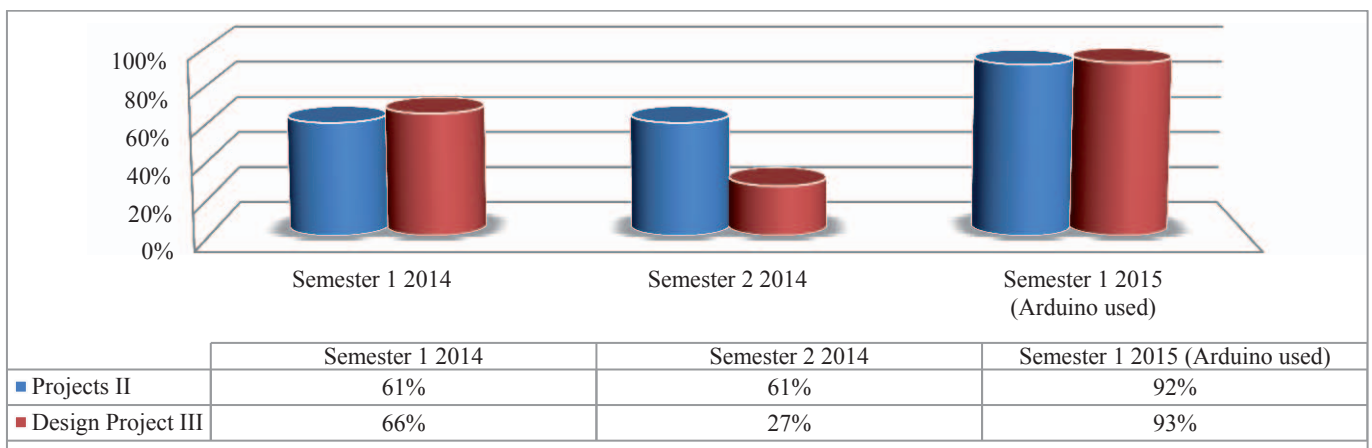


Fig. 7. Final results of Projects II and Design Project III

VI. DISCUSSION OF RESULTS

A total of 64 students enrolled for Projects II and Design Project III during the first semester of 2015 ($n = 64$). Due to the fact that the main difference between the two modules relates to various levels of complexity, the results of the questionnaires were combined. 68% were male with 32% female, substantiating the fact that engineering tends to be dominated by males [24]. 79% were between 20 and 24 years of age with 17% between 25 and 29 years, highlighting that the majority of students have no previous higher educational qualification as they have just completed their school career [25]. The survey indicated a total of 8 different home languages which is in line with the fact that South Africa has 11 official languages [26]. The predominant home language was Sesotho, which is spoken by the majority of people living in the Free State, where CUT is located.

At the start of the module, 66% of the students indicated that this was their first encounter with a microprocessor. This suggests that the effective use of the Arduino would maybe prove challenging to these students who had little or no design based experience. This was also reflected in 50% of the students who felt that they did not find it easy to get started with the module. This corresponds with previous literature that states that students who have no previous programming experience do find it difficult to start designing with Arduino [27]. Furthermore, at the beginning of the semester, every student was given an Arduino Uno board to use and return at the end of the semester. The provision of this board did not really help all the students to get started with the design of the project (see Figure 5). This may be linked to research done by Beckman and Barry [4] who describe how students struggle with design principles regardless of the process used to teach them. However, eventually 91% of the students felt that their interaction with the Arduino helped them to better understand the theory of design (see Figure 6). This is supported by the thematic theme reported on in Table 3, where 70% of the students made the comment that the module helped them to better understand the theory. This does suggest that the Arduino microprocessor can be successfully used for DBL in a design-based module to enable students to grasp fundamental design principles. This is further confirmed by the pass rates of the two modules, which increased by more than 30% and 45% respectively with the use of the Arduino platform. This intervention has indeed contributed to greater academic success for these engineering students.

More than 90% of the students indicated that they would encourage other students to take the module, while 93% stated that the module was a valuable learning experience for them. This was also confirmed by the fact that 70% of the students revealed that the module helped them to gain valuable knowledge. This may be interpreted as an indication of student satisfaction, which can result in more motivated students. Motivated students do better academically and contribute to a better learning environment for other students to benefit from [28]. Student satisfaction with the module and the use of the Arduino microprocessor may further be discerned by the thematic themes reported on in Table 3. 62% of the students indicated that the module was a good learning experience while 36% revealed that it was interesting, fun or enjoyable.

The significance of student satisfaction is widely reported on in literature [29-31]. Satisfied students will among other things make positive recommendations to other students [32], continue their study until graduation [33], provide word of mouth marketing for higher educational institutions [34] and have a general positive influence on the educational process.

The use of many different sensors during the semester is an indicator that the integration of sensors with the Arduino platform is not too difficult for students to master [35]. The ease of use of these sensors empowers the students to do more complex and creative designs in reasonable time. Creativity is an important principle of DBL, as it demonstrates the important attribute of creative thinking [9]. Furthermore, programming skills are an important attribute of electrical engineering students [36], while design skills are an important graduate attribute of many engineering courses [37, 38]. The thematic themes (reported on in Table 3) revealed that 36% of the students made the personal comment that this module helped them to improve their programming skills, while at least 26% reported an improved skill of problem solving. 64% of the students reported an improvement in their design skills. This again re-iterates that the use of the Arduino microprocessor has enabled students to acquire important graduate attributes, which they may use to contribute to the socio-economic development of their communities.

Finally, students indicated that they found it easy to get information and examples about the Arduino on the Internet. This is in line with literature that indicates that a large community of Arduino users and supportive material may be found on the Internet [39].

VII. CONCLUSIONS

The purpose of this paper was to illustrate how the Arduino technology was used in two design-based modules, termed Projects II and Design Project III, and how undergraduate engineering students benefited from its use. The learning outcomes of these two modules were presented in the subsection entitled "Context of this study", and focused on the writing, presentation and design skills of students. However, this paper only reported on the design skills of undergraduate engineering students in the two design-based modules.

Four significant results were found. Firstly, while students initially reported difficulty in starting their design with the Arduino microprocessor, eventually 91% of them felt that its use did help them to better understand the theory. Secondly, student satisfaction with the module was inferred by the number of student who stated that it was a valuable and good learning experience and that they would recommend other students to register for it. Thirdly, the use of many different sensors helped to develop student creative thinking, as their programming, problem-solving and design skills were improved. Finally, the dramatic increase in the pass rates of these two modules indicate that the Arduino microprocessor can be successfully used in a design-based module to enable students to grasp fundamental design principles, thereby enabling academic student success.

It must be noted that this study was limited to a singular group of students in one semester. Employing a time-lag study

will enhance the reliability and validity of the results. However, this study has revealed that if students are given the right tools, such as the Arduino microprocessor, then they will do wonderful things with them to their personal benefit.

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