Teaching Programming using Arduino-based Educational Frameworks

A Project Proposal

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ABSTRACT

This project proposes introducing novel ways of testing students by building Arduino-based Educational Frameworks in the form of programming assignments to allow students to see physical results from their code and attempt to increase motivation to complete the assignment as well as to investigate further topics introduced in the assignment. This is necessary as students are feeling increasingly overwhelmed by the Computer Science curriculum, and finding it difficult, resulting in declining enrollment and high dropout rates. Clearly introducing a fresh approach is necessary to educate people in a skill that is quickly becoming a necessity in the modern world.

Three Educational Frameworks will be produced with associated documentation, and will follow a scaffolding approach suggested by the literature, in which the code will contain missing parts that will be specifically targeted to examine Computer Science topics and skills. The hardware will also follow a similar skeleton approach, so that students can build the required system in the allotted amount of time.

The three Educational Frameworks will be built with differing structures to investigate different areas which may interest students. The first will be a games-based approach which will seek to combine students' interest in games with hardware in order to stimulate and motivate them towards not only applying their coding skill but also implementing electronics to produce a simple handheld game console. The second project will implement a networked alarm system that will alert a user to an intrusion via a message on their phone, this will attempt to introduce advanced topics such as networking in an interesting and interactive package.

CCS Concepts

•Applied computing → Interactive learning environments; •Hardware → Sensor applications and deployments; Sensor devices and platforms; *Displays and imagers; Networking hardware;* **•Human-centered computing →** Handheld game consoles;

Keywords

Education; Microcontrollers; Arduino; Programming; Game Framework

1. PROJECT DESCRIPTION

Programming knowledge is fast becoming a necessity in the modern world, knowledge that is necessary for not only computer scientists, but also designers and engineers looking to create interactive prototypes[1]. Computer Science and IT related professions are also considered scarce skills in South Africa[9][18].

Despite this need for people to become literate in programming, many find introductory programming courses difficult[10][13][14], resulting in high failure rates[17][2][3] and declining enrollments[17][21][15][8][2].Furthermore students lack motivation to complete the course[13] and find the content and assignments boring[13].

It is clear that a new approach to introductory Computer Science education is required, one that introduces the topics in a novel and engaging way to students. Two methods that have currently been employed are the use of game-based assignments[21][22][17][7][8], and the use of microcontrollers, specifically the low-cost, open-source Arduino boards[20][12][5][6][1], both have been successful in stimulating interest in students and motivating them to complete their assignments and investigate further topics in Computer Science, even in the case of game-based assignments being considered easier than traditional assignments, despite evaluating the same knowledge[7].

The Arduino is an open source hardware project that has created a series of microcontrollers designed for users to build hardware devices and interactive prototypes. The Arduino board is coded in The Arduino Language (a set of C and C++ functions) via an open source IDE.

This project will attempt to introduce students to basic Computer Science topics by giving them Arduino based Educational Frameworks in the form of assignments where they build a game, a networked alarm system and a digital musical instrument, in the hope that this can help to engage students by giving them a physical relation between their

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code and the real world and provide them with additional motivation to not only complete the assignment, but also become interested in further study in Computer Science.

Our research is necessary since it will assist in understanding the relationship between the novelty of the topic selected to teach programming and student interest in programming. Since creating new assignments and implementing new teaching methods requires a lot of time and effort from lecturers who may not have previous experience in the topics of games[22][21] or microcontrollers and it may be expensive for the university to buy a microcontroller for every student in an introductory programming course, our research will assist lecturers to better assess whether or not implementing such assignments is worth the effort, as well as providing three complete and tested assignments that can be introduced into the curriculum with minimal effort.

2. PROBLEM STATEMENT

Through our research, we aim to understand whether or not a new and potentially more interesting approach to Computer Science assignments using Arduinos to provide a physical link between the code and the real world could engage students interest and motivation to complete the assignment and even learn more. We seek to answer the following questions with our research:

- Can Educational Frameworks base on Arduino microcontrollers improve student interest and engage them in the study of Computer Science?
  - Can Arduinos and games, both successful in raising student motivation, be combined to increase student motivation and interest in Computer Science?
  - Can a networked alarm system interest and engage students in a Computer Science Educational Frameworks?

These questions are important as their answers could assist in the implementation of Educational Frameworks and assignments in the future, so that students can become further engaged and interested in Computer Science.

3. PROCEDURES AND METHODS

In order to investigate the Research Questions a qualitative analysis will be done with first year Computer Science students. The students will be given the three programming assignments to complete as well as the Arduino boards and electronic components. The students will be recruited from those that completed the CSC1011H course at the University of Cape Town as they have had some lectures on Arduino programming and so would be the exact set of users our assignments would be aimed at, additional students will be recruited from the CSC1016S class as they will have completed some Java thus having some experience with a curly braces C-style language, and will be given a quick Arduino primer course. Using students from both these courses will allow statistically significant sample sizes.

The code for the Educational Frameworks as well as the breadboards will be partially complete in order to test a specific programming and electronics skills. Providing students with a skeleton enables them to focus on a specific problem area without having to think of the larger program or device structure, as their experience is in smaller programming projects. This skeleton will have to be investigated to determine what the optimal incomplete solution is, such that the students can complete the assignment while it still being sufficiently challenging, this is not part of the evaluation and will be completed informally in consultation with Gary Stewart, only one level of scaffolding will be available to the students. The content for the Educational Framework will be investigated with the lecturer of the CSC1011H course, Gary Stewart, in order to ascertain what topic (or combination of topics) are suitable for examination given the students knowledge and skillset.

The code will be written in The Arduino Language and will be run on the Arduino boards attached to the students' PCs. The students have already received instruction in The Arduino Language and the basics of Arduino programming and design as part of their CSC1011H curriculum, and as such the assignment will test the students' overall knowledge.

The game based Educational Frameworks will be chosen from one of three simple games, namely a multiplayer tick-tack-toe game, a Tetris clone and a racing game. Through discussions with the CSC1011H lecturer and a survey delivered to the students, the final game will be chosen based on interest as well as viability.

The students will not be graded on the assignment but their final product will be collected and evaluated, in addition to this code evaluation (from which an error rate will be calculated) the completion rate of the participants will be recorded, and they will be asked to complete a survey following the assignment where they will indicate their levels of motivation and interest in the assignment and compare it to other assignments they have completed, they will also be asked to rate the difficulty of the assignment and compare it to other assignments they have completed, this evaluation will be built on a Likert scale. This project will be successful if there is a significant positive reaction to the assignment from the students and their final code and breadboards are complete and working, indicating that they not only enjoyed the assignment but also were able to complete it in a satisfactory manner. The survey will be analyzed using statistical methods in order to draw accurate conclusions from the data.

A challenge that may be encountered is that the development team does not have an intimate knowledge of the Arduino Language, and C (which is the basis for the Arduino Language) itself is more difficult than the introductory language, Python, used in first year Computer Science at UCT. This will be overcome by making use of the standard set of control structures that students know already (loops and if statements) and not more complex C constructs such as pointers. The students will also have already completed an introductory module on the Arduino as part of the CSC1011H syllabus, and the development team have had an introductory lecture, and completed some self-study in the Arduino Language and Arduino programming.

4. ETHICAL, PROFESSIONAL AND LEGAL ISSUES

Because research will be done with students we are required to obtain ethical clearance from the university.

The Educational Frameworks will be built using open source tools and libraries and the final result will be available as an open source project.

5. RELATED WORK

After reviewing previous literature, we have observed the positive effect that learning programming as a tool to be applied in a different field has on student interest and understanding of various programming concepts[16][19][1]. In these articles, the students enrolled in the courses did not have previous experience with programming, but felt motivated to learn programming concepts in order for them to create better products.

The use of Arduinos in attempting to teach programming in a more interactive way has also been researched [11] [4].In these articles, visual programming languages such as Scratch and Modkit Alpha were used with Arduinos to teach programming in a more tangible way. A common problem that existed in the articles was the fact that the students enrolled had no prior experience in electronics. This problem was averted in the Scratch class by making use of a programming language called S4A, a scratch modification that makes it easier to make programs for Arduinos. In the Modkit Alpha class, the researchers pre-prepared prototypes of the electronic circuits before class and gave them to students.

Games have been shown to increase student motivation[17][8], with many students choosing game related assignments over traditional ones for reasons that include a perceived lower difficulty and more knowledge of how the game works[7][8]. Games can also interest students in more advanced topics such as networking, databases and artificial intelligence[15]. They can also be implemented to test the same content as a traditional assignment[17][21] but are however more difficult for lecturers to implement, especially if they have no experience in games or computer graphics[22][21]. The literature does recommend using scaffolding (providing the code with some parts missing) when producing a game based assignment so as to focus the student on a particular topic[2][10], this can be extended to scaffolding a breadboard setup for students to complete.

The research conducted on these topics however only looks at how programming education can be improved by teaching it through the discipline at hand, e.g, through games or fashion design. Based on the fact that these studies were done at different times and under different conditions, we can not conclusively say that programming education can be improved when used as a means to be applied in another field.

6. ANTICIPATED OUTCOMES

The core aim of our project is to get students to develop a greater interest for programming beyond what they are taught in class. Through giving students an assignment based on the Arduino platform, students can see physical results from their code, and extend their Computer Science knowledge to other fields. Another aim is to reinforce a culture of creativity within students by getting them to create something unique.

In order to measure the success of our research, a survey will be conducted with the students involved in the research. Through the survey, the students will answer a series of questions centered around whether or not they found the assignment interesting, if the novelty of the assignment made implementing programming concepts easier and if they are inspired to apply the concepts they have learned beyond their university assignments, as well as rating and comparing the enjoyment and difficulty of the assignment with others they have completed. The project will be considered a success if there is a positive response to the surveys and if the students are able to complete the assignment within the allotted time. The expected impact is that our assignments can be used within a standard introductory curriculum in Computer Science, programming and microcontrollers such as the CSC1011H course. This will help in enriching the curriculum with an assignment that is interesting and motivating for students, without any additional work by the lecturers.

The Educational Frameworks will be evaluated independently, to determine whether they increase student motivation and interest, the results then be compared to determine which assignment is most effective.

The research will be carried out through the creation of 3 distinct Educational Frameworks as assignments for students. The group of students will be divided and allocated an assignment group. The common theme behind the assignments will be the use of an Arduino microcontroller. The assignments will be: The creation of a game, a networked alarm system and a digital musical instrument. The assignments will be implemented as a scaffold of code and an incomplete circuit that the students must complete.

The experiment will be conducted within a duration of 2 hours,with students being given the necessary materials and instructional guides to complete it. Each student will be allocated a tutor who will be available for assistance for the duration of the tutorial.

The Educational Frameworks will be built around using the features of the Arduino microcontrollers as well as electronic components, including LCD screens, LEDs, buttons, motion sensors and electronic components such as resistors. Students will get the opportunity to program the microcontroller, as well as to dive into some simple electronics.

Expected problems are time constraints and deciding how much scaffolding and support to give to students in the implementation of these Educational Frameworks. Additional anticipated problems are students not understanding the necessary electrical concepts to complete a circuit. As well as the overhead in learning the Arduino Language for both the developers and the students (although both will learn it ahead of time).

7. PROJECT PLAN

7.1 Resources

The resources required for this project will be the Arduino microcontroller boards, and the requisite electrical components including breadboards, cables, screens, buttons, motion sensors, buzzers, resistors and LED lights. The students will each be given the Arduino and a partially complete breadboard on which to complete the assignment. They will also need to have access to a PC on which the Arduino IDE is installed (The Arduino IDE is opensource and runs on all major desktop operating systems), the students will be provided with skeleton code to complete.

The game based Educational Frameworks will make use of

the LED matrix for displaying the game graphics and a LED number display to display the score. In addition buttons will be used for input and additional LED lights may be used for system status (for example in the racing game red, yellow and green LEDs may be used as a countdown to the start of the game).

In addition to the hardware and software, students will be recruited to evaluate the assignments. The students will be recruited from those that completed the CSC1011H course at the University of Cape Town. The lecturer of the CSC1011H course will assist in recruiting the students.

The online Arduino protoyping software suite 123D by Autodesk will also be used in order to quickly prototype and test the design of the assignments before they are implemented on the physical Arduino boards.

7.2 Risk and Management Strategies

The table below details the project risks, impact of the risks, likelihood and mitigation strategies in our research project. Note that the W stands for Weighting, and the L stands for Likelihood. The weighting and likelihood occur on a scale of 1 to 10.

Table 1: Table showing risk matrix for the project

Risk	W	L	Mitigation
Loss or physical damage of the Arduino components	8	5	Carry out experiments in class
Students overloading circuits on Arduino boards	8	4	Provide instructional diagrams on assembling circuits
Faulty physical components	9	2	Test components before giving them to students
Students being too busy to take part in project	9	6	Agree on dates for experiment with students in advance
Lack of student interest for research	9	5	Provide participation certificates and a raffle to win a voucher at a store
Necessary physical components that were unaccounted for	6	2	Create a budget for unaccounted physical components

7.3 Timeline and Gantt Chart

Figure 1 shows the Gantt chart highlighting the timeline from the proposal submission, through the development, to the submission of the final report.

Due to the use of the 123D online platform the hardware will only be required from the 11th of July, where only 3 boards are necessary for final testing and the 19th of July when the production of the skeleton boards will begin.

The students will be required during the period of 25 July to 5 August, during which a number of small sessions will be run with as many students as possible to ensure an adequate sample size.

Following this the data will be evaluated and the report written up.

7.4 Deliverables

Each member of the group will produce a complete Educational Frameworks that makes use of the Arduino board. The Educational Frameworks will consist of an instruction sheet, a complete implementation of the code, an implementation of the code in which one or more sections are removed for the students to complete, two circuit diagrams showing the complete circuit and the incomplete circuit. These deliverables will allow anyone to make use of the Educational Frameworks in their curriculum with minimal effort.

In addition to these deliverables, a complete circuit and a number of incomplete circuits will be implemented for the user testing phase.

The three individual projects will each produce these deliverables, but each circuit and code will be different to test a different aspect of the introduction of Arduinos into the syllabus. Mitch will produce a game based Educational Frameworks that will integrate the Arduino so that students can build a basic handheld game console, the type of game will be determined based on student and lecturer feedback, and will not be part of the evaluation, but will be a preliminary investigation; Tumelo will produce a networked alarm system to potentially interest students in home automation.

All the deliverables are listed in Table 2:

Table 2: Table showing deliverables for the project

Deliverable	Due Date
Proposal	17 May 2016
123D Prototype	11 July 2016
Assignment Leaflet	5 September 2016
Electronics Diagrams	5 September 2016
Draft Submission	17 October 2016
Final Paper Submission	31 October 2016
Code Submission	31 October 2016
Poster Submission	7 November 2016
Web Page Submission	11 November 2016
Reflection Paper Submission	14 November 2016

7.5 Milestones

Figure 1 shows the timeline of deliverables and milestones. The milestones are listed in Table 3:

7.6 Work Allocation

The project is divided into three parts, with each member contributing a separate Educational Frameworks in the form of an assignment (as well the requisite documentation for using it) along a different theme: namely a game, an alarm and a musical instrument. The assignments will be coded in the Arduino Language and a full example will be coded and developed both on the 123D simulation and on the physical Arduino. The assignment skeletons will also be produced

Table 3: Table showing milestones for the project

Milestone	Completion Date
Proposal Presentation	25 May 2016
Code and Skeleton Complete	5 September 2016
Documentation Complete	5 September 2016
Skeleton hardware complete	9 September 2016
User Evaluation complete	19 September 2016
Report Skeleton Complete	30 August 2016
Paper outline complete	14 October 2016
Paper Draft Complete	17 October 2016

along with an electronics skeleton for each tester, as well as detailed diagrams for building the complete system and the skeleton system. Each member will additionally complete a user evaluation of the assignment with students and will evaluate their final product against this.

8. CONCLUSIONS

The importance of students effectively learning programming can not be understated. The constant shift of the world towards storing and interacting with information digitally means that as time goes by, more people will be required to learn programming concepts, so it is important for programming classes to be as appealing to people as possible, and to end the stigma that computer programming is boring and difficult. With novel approaches it may be possible to engage more young people in Computer Science and stem the tide of falling enrollments and high dropout rates. The aim of the research is to find what impact novelty has on student interest in programming so that lecturers can be better informed in how to structure their assignments. Since three distinct Educational Frameworks will be created, we anticipate problems with carrying them out however we have put the necessary mitigation strategies in place.

The three Arduino-based Educational Frameworks are a game-based assignment where students build a small handheld game, a networked alarm system that pings your phone when tripped and a musical instrument. All of these are novel approaches which seek to stimulate the interest of students and motivate them to expand their skills in computer science.

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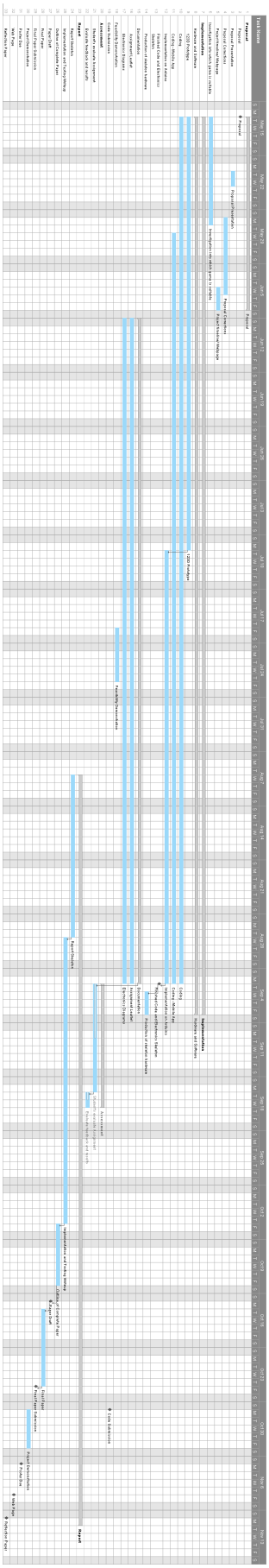

Figure 1: Gantt shart showing the timeline for the project (readable when zoomed in)