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A Project-based Learning approach for teaching Robotics to Undergraduates

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Abstract. In this research we used a project-based learning approach to teach robotics basics to undergraduate business computing students. The course coverage includes basic electronics, robot construction and programming using arduino. Students developed and tested a robot prototype. The project was evaluated using a questionnaire. The evaluation result shows that students developed skills in circuit design, problem-solving and robot development for addressing real world problems and team work. The students had challenges of using limited resources for robot circuit design and construction. The research results indicate that robotics education through project-based learning motivates students to learn and implement computer artefact that addresses real world problems.

Keywords: Robotics; Project-based learning; ICT.

1 Introduction

Robotics is a fascinating discipline that easily engages computing students. Educational robots are stimulating and motivating (Soto, Espinace & Mitnik, 2004; Hamblen & Hall, 2004; Alves et al, 2011; Howard & Graham, 2007), there are good reasons for introducing robotics activities very early in course curricula, and this allows students to easily perceive the relationships between undergraduate courses, in their theory and practice.

Experience has shown that better learning happens when students are engaged and motivated (Galvan, Botturi, Castellani & Fiorini, 2006; Mok, 2012; and Pink, 2009). According to Alves et al (2011), robotics can be used as a motivating element, and Rawat and Massiha (2004) verified that student feedback after robotics class was overwhelming positive. Educational robotics recommends the use of robots as a teaching resource that enables inexperienced

students to approach topics in fields unrelated to robotics. One of its objectives is to aid students in building their own representations and concepts of science and technology, through the construction, handling and control of robotics environments, as well as through collaboration teamwork. The main idea is that knowledge is constructed rather than being discovered, and that studentsô learning significantly improves when they participate in building something meaningful to themselves. These approaches are based on educational theories such as Piagetôs constructivism (Piaget, 1967).

1.1 The significance of robotics education

Science and technology have gained popularity among the youth today. These disciplines when introduced earlier in education can motivate students to develop careers in science. With progress in technology, the accessibility of robotics to children in lecture room has improved. Two decades ago, robotics kits for students were limited to simple structures and motors but now they include a multitude of sensors and motors as well as the interface with desktop computer to allow for robust programming experiences, all at affordable cost making them accessible to the classroom.

Kits in classroom learning are valuable in classrooms and they help to attain the following:

1) *Hand-on learning and engagement:* Students of all ages enjoy hand-on construction activities. In these practical activities children demonstrate competence in many different subsystems that involve structure, motion, sensors, programming, and manipulation; these bring opportunities for them to find something that suits their particular interests.
2) *Problem solving and training for future careers:* Robotics enables students to become problem solvers as they develop robots that have well defined tasks to accomplish before the actual construction of the robot begins. The design process used by engineers begins with understanding the capabilities and limitations of their tools and equipments, researching and getting to understand the existing problem, conceptualizing a solution to that problem, constructing the envisioned solution, testing the solution to find its performance, and revising the solution based on this performance.
3) *The inclusion of a computer programming allows for deeper understanding into issues such as remote sensing, control, and autonomous functioning.* The issues faced when constructing and building a robot promote better appreciation of what nature achieves in smaller and lighter packages.
4) *Creative ways to keep the learning going:* Many projects in robotics have been successfully developed children using robotics kits in lecture room or laboratory settings. Some of the projects worth noting include:

a) *Adaptations.* Here students develop complete robots using minimum resources given in the robot kit. The design should not sacrifice speed and other important functional requirements of the robot.
b) *Genetics.* The structure of an organism is determined by the components that comprise it. The students need to spend some time to study the components of an organism and after that they should come up with a challenge and construct a robot to address the challenge.
c) *Language arts:* Writing of project manuals, technical manuals, documentations can be incorporated into robotics project, and the outcome can be posted on the Internet to add an additional technology element to the project.

1.2 Research Motivation

Robotics education has not been implemented in institutions of higher learning in Uganda. This has created digital divide in this ICT discipline between Uganda and other countries where robotics is taught and robots are practically developed by students in laboratories. Students can creatively apply robotics knowledge and skills to solve real world problems. In this project, a group of students construct and test a robot to demonstrate how robots can save mankind in difficult situations like earth quake, flood, war and other natural disasters. The major objective of this research was to develop working prototype of a robot using project-based learning approach in order to demonstrate the capability of robot to solve real world problem. In particular, the requirements necessary and available for design of a robot were established; the robot prototype was developed and tested to demonstrate the functionality of the sensors. The research has created robotics education awareness in the student community and it has also demonstrated application of computer technology to solve real world problems.

2 Methodology

2.1 Project-based Learning

Project-based learning or problem-based learning is defined as a learner-centred approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem (Savery, 2006).

In a traditional learning environment, students are taught a new course using lecture approach. After introducing a problem, a project is then given to

students to find solution either in the lecture room or in a laboratory, based on the course already taught. On the other hand, in a project-based learning, real world problems or projects are first presented to the students and these problems or projects become the focus for teaching and learning directed by a teacher. The students begin to learn specific subjects and attain generic skills to solve problems or do those projects.

Project-based learning provides students with generic professional skills such as problem-solving ability, team skills, and the adaptability to change, communication skills, self-directed learning, and self-assessment skills (Woods, 1995).

A project-based learning approach has proved to be successful in teaching engineering courses as it provides a successful mechanism to help students achieve high-level learning goals and deal with real problem-solving activities. In project-based learning, the instructor has a less central role, and students are more responsible for their own learning, which results in higher learner-centred approach in the learning environment (Andersen, 2002).

In this research project, students developed a rescue robot using problem-based learning approach. The students were first introduced to basic electronics and circuit design, this was followed by programming of robot actions using arduino open source software development environment. The students assembled the components of a robot to get a working robot prototype shown in Figure 1:

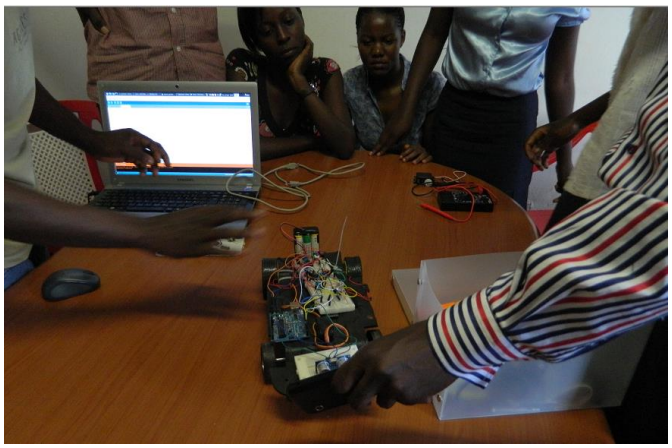

Figure 1: Robot development

2.2 Electronic Components for Robotics Project

The electronic components which were used by the students to develop the robot prototype are shown in Table 1.

Table 1: List of used electronic components

• 2 x Arduino Duemilanove • 3 x Breadboards / Prototyping boards • ~ 50 x Jumper wires • 16 x Rechargeable batteries • 3 x Battery cases • ~30 x Leds (different colours) • ~50 x Resistors (different sizes 100ohm – 100K ohm) • ~20 x Capacitors (different sizes) • 3 x 5V Regulators • 3 x Photoresistor	• 1 x Thermoresistor • ~ 20 x Diodes • 4 x L293D motor controller • 4 x DC-motors • 4 x Servo motors • 6 x Switches • 2 x Ultrasonic sensor • 1 x Liquid crystal display (16x2) • 2 x Potentiometers (10K ohm) • 10 x Transistors (NPN) • Piezo buzzer • 4 x Buttons

2.3 Development environment: Arduino

Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It's intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments. Arduino can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. The microcontroller on the board is programmed using the Arduino programming language (based on Wiring) and the Arduino development environment (based on Processing). Arduino projects can be stand-alone or they can communicate with software running on a computer. We chose to use Arduino-board because of the easiness of use. It is fast to get in and learn. There is also great amount of material that can be freely found from internet. Most of the materials are constructed by common hobbyists working for the benefit of the community. This material was also used in explaining the opportunities within Arduino's environment. òThe open-source Arduino environment makes it easy to write code and upload it to the input/output board. It runs on Windows, Mac OS X, and Linux. The environment is written in Java and other open source software. In Arduino's website there is a free programming environment provided. Environment contains all the essential tools for getting started with Arduino development.

3 Evaluation of Project-based Learning for Robotics Education

The project was evaluated using questionnaire with open-ended questions. The evaluation results show that students acquired skills in electronic circuit design, programming, problem-solving and robot assembling. The students are also ready to promote robotics education among the studentsô community by

creating awareness of the value of robotics in society. The evaluation results are summarized in the section below. The following is the evaluation criteria.

1. Purpose of the course
2. Knowledge/skills gained
3. Opportunity to study robotics
4. Challenges experienced in robotics project
5. Suggestions for course improvement
6. Robotics course awareness creation
7. Robotics applications for development
8. Robotics learning resources

3.1 Purpose of the Course

The students were asked to state the purpose of the course they had done in the project-based learning activities. This was asked to test their appreciation of the course and to find out their individual aims in the course. The following responses were given:

1. ñTo equip us with necessary skills up and beyond what we were studying.ò
2. ñTo equip us with robotics building and programming skills.ò
3. ñTo learn basic electronics and how implementing natural science to help improve our daily lives.ò
4. ñTo equip me with the basic knowledge about robotics. Like what they can do, the different tools used in designing them, and also to be able to come up with a robot on my own and also pass on the knowledge to other students.ò
5. ñTo introduce the concepts of robotics that is to say the coding of a robot, the basic components to use in assembling a robot, how to connect the different parts in order for the robot to work smoothly.ò
6. ñTo equip students with the knowledge of how robotics are developed and their purpose in the community.ò

3.2 Knowledge and Skills Gained

The students were asked to list everything they learned in the course. This question was asked to find out the skills gained and knowledge acquired by students in the two and half months of the project. The students responded with the following statements in quotes:

- ñI learned how to program robots.ò
- ñI learned to use arduino software environment.ò
- ñI covered some electronic basics.ò
- ñRobotics technological environments like operating a robot from a distance e.g. the mars rover project.ò

- ñI have managed to learn programming in C++ using arduino and some bit of java programming.ò
- ñI have got knowledge about basic electronics and how some of the appliances we use work.ò
- ñMy knowledge sharing skills have been improved through consulting and passing on the different ideas to other group members.ò
- ñI have learnt how to work as a team and ho to assign tasks to different to members so as to a chive the set objectives within a particular period.ò
- ñI have been equipped with teaching skills through explaining to the team members the different ideas and basics that I had acquired from the different sources.ò
- ñI learned to unite and share different ideas from other students with in the project to come up with a final robot we all needed to design using the different tools. For example we used arduino and blink application through their libraries and examples (my servo, blink, distance) during the coding sessionôs I was able to upload the different codes into the arduino raspberry board which was connected to our simple robot so that it could execute the different tasks assigned to it.ò
- ñI connected different parts like the servo motors which cause the turning effect and DC motors, resistors, light emitting diode, light dependent resistor(to measure the reflection of light), diode, switches, sensor (SRO4), regulator, resistors,L293D,masking tape using the different wires on to the board.ò
- ñI used the soldering machine to solder different wires on the switches, used the multi-meter to measure the voltage and amps for the resistors.ò
- ñDuring the connections I should always ensure the board is not powered to prevent the circuits or in instead use diodes in case of any wrong connections.ò
- ñOnline controlling of a robot in Finland while following and basing on the compass direction, humidity and spectrum to detect the magnetic fields.ò
- ñI have learnt that making/establishment of a robot is not a hard task therefore to be left for only the white people but we the black people can manage to establish our own robots.ò
- ñI have also learnt that a robot does not only mean a moving metallic artificial creature in form of a human being but it can also be in any other form.ò
- ñI have also learnt that in order to code a robot to move and do some tasks, you neednôt to be familiar with a lot /many programming languages but depends on some oneôs commitment.ò

- ñOn addition to the above, I have learnt the different basic components to be used in assembling a robot, their names, their purposes and how to connect them in order to achieve my goal.ò
- ñI have also learnt how code /program a robot according to what I want my robot to do. This involves an understandable programming format, as well as the commenting of the code for easy usage or makes it easy to understand what the code does.ò
- ñI have learnt that a human is capable of doing anything so long as there is teamwork and corporation among the people involved in the activity. For example we were in position to come up with a simple rescue robot due to teamwork and corporation.ò
- ñI also learnt the coding of the programs using languages like oracle, visual basic and c ++ in order to come up with a working prototype.ò
- ñI also learnt how to connect various components like the led, the sensor, motors, connecting wires, resistors and jumpers among other components.ò

3.3 Opportunity to Study Robotics

An opportunity to study robotics in projects was also investigated. The students were asked whether they would be willing to participate in more robotics projects in the future. The following were the responses given to the question:

- ñI really feel and believe there is so much more I can do apart from this. The sky is the limit.ò
- ñYes I believe I can develop a robot which can monitor a particular area.ò
- ñYes! If I have all the basic parts I can educate the other students who are not part of the group the basics of robotics.ò
- ñYes I feel there are other projects I can do in future apart from what I have done. For instance in future when I have enough funds, I want to start a project on establishment of a more advanced robotò
- ñYes, I feel I can come up with a robotic that can be used in organizations to deliver products to their different destinations. Like papers from one office to the other.ò
- ñI feel I can also come up with a robotic that can be used in hospitals to take medicine to respective patients and it can help in cleaning the hospital.ò

3.4 Challenges Experienced in Robotics Project

Students were asked to give challenges they experienced when learning robotics. The responses given include technical issues, personal challenges and infrastructural challenges. The following were the studentsô statements:

- ñI had no laptop yet it was an essential requirement on the programming side of it. There were a few parts available for all of us. The time of study sometimes conflicted with personal obligations.ò
- ñLimited internet access which slowed down the learning process.ò
- ñInsufficient materials to implement all the Ideas that I had and those from the club members.ò
- ñLimited time that was allocated to the project since it was running within the semester (at the same time with school programs).ò
- ñA power shortage since my laptopôs standby battery is not functional.ò
- ñI was not much familiar with most of the parts ñelectronicsò and I had less physics knowledge. So at first I found a lot of hardships in the connections and also coding in arduino was complex it needed a lot of time to understand the different steps.ò
- ñThe connection of the different components was not easy at the beginning since it needed knowledge of physics. For example measuring of resistance among other thing that I was not familiar with.ò
- ñThe components were not enough for the students to incorporate in the system prototype.ò
- ñThe coding of the program involved using of c++ language, in which I lacked enough knowledge.ò
- ñThe timing of the project was also unfavourable since it was conducted during the course of the semester hence we could not concentrate much in the project due to other academic work.ò

3.5 Suggestions for Course Improvement

The students were asked to give suggestions for improving robotics course. They expressed many issues mainly with limited resources for the course and having limited expertise to learn everything in robotics within the given short timeframe. The following responses were given by the students:

- ñBy getting or making more research on the programs needed for robotics. By improving on my Arduino programming. By innovating other ideas on how to integrate robotics environments to business. More robotics parts to facilitate the building part of it. More time required for the robotics workshop. By putting up a robotics Club which can help in spreading the knowledge about robots and a whole.ò
- ñI think we can improve the workshop through research and implementation of the various ideas shared over the internet.ò
- ñThrough providing support as a tutor to train other members who might be interested in the project.ò

- ñShare the positive ideas with different people with the potential to support the project.ò
- ñUsing the project as a source to solve some of challenges faced by the community I live in.ò
- ñI would increase more working parts to be used at least an arduino to be used by a group of three to two students.ò
- ñI would also award gifts to the best designers so that I encourage the others to work hard and acquire them.ò
- ñI would also introduce the robotics basic knowledge to the young minds. E.g. students of o-level classes so that they grow up with the passion of doing it and understand more of the physics techniques since it works more with electronics.ò
- ñThe major and main challenge I faced while working in robotics was managing time for the studies and the robotics project.ò
- ñThe other challenge was lack of my own machine (laptop). This was also a challenge to me because I after leaving the workshop area I could not add or revise through what we had done that day.ò
- ñThe other challenge that I faced was learning how to code the alduino so that to enable the robot to work smoothly.ò
- ñThe project should be carried out during holiday such that the students have enough time for the robotic project.ò
- ñMore components should be available to the students in order to come up with a better prototype that can give to the end-users for evaluation.ò

3.6 Robotics Course Awareness Creation

The students were asked whether they would encourage fellow students to learn robotics. This was asked to find out the level at which they value robotics and how they can promote robotics education in the University. The following responses were given by the students:

- ñIt is one of the first things one can ever be involved in. It widens our innovation and technological scope. Students should make a way or even develop positive attitudes about robotics. Robotics can be the new centre of development.ò
- ñI would advise all students especially computing students to take up robotics not only as a hobby but also as a way of acquiring hands on skills, more knowledge to support their computing carrier and competence and to put in practice what they have learnt.ò
- ñI would advise them to have passion interest and patience in whatever robotic project they would be taking up. Because robotics education needs a clear mind which can generate different ideas, itôs all about creativity and

most of the parts used in designing them are common and easy to work with. Though most people think to come up with a simple robot is something so hard ñwrong perceptionòò

- ñThe advice I would give other students is that in case any other opportunity comes there way regarding robotics education, they should not let it pass because it makes them get familiar with technology since itôs the way to go.ò
- ñI would advise my fellow students to always come up with boldness whenever there is an opportunity to do anything for example in such a project. Student should not fear but instead just pick in interest in the research project.ò

3.7 Robotics applications for development

The students were next asked to suggest areas in which they feel robotics can be applied to determine solutions to real world problems. This question was asked to test the studentsô problem-solving skills and technology applications to real world problems. The following responses were given:

- ñRobotics can easily become a very valuable investment tool under both the private and public sector. Employment explosion, which can increase on the standard of living. It can develop the export / import sectors (Trade). It can contribute to the work output and input in the corporate market.ò
- ñTechnological advancement.ò
- ñI think Robotics can help to improve on the mode of education delivery where various models can be developed for demonstration purposes such as storytelling.ò
- ñRobotics can also promote the level of innovation among the citizens through modifying various equipment to suit their different needs hence reducing on the costs of importing such technologies or equipment.ò
- ñIt can also help to reduce on the costs of living where people wonôt have to always pay for the basic connections and repairs in their day to day domestic appliance.ò
- ñRobots reduce on tiresome, manual work in an organization since robots do not become tired.ò
- ñThey can also be used to improve security measures.ò
- ñThey also improve on communication in Uganda.ò
- ñI think robotics contribute in the development of Uganda when implemented in the information technology (IT) departments of Uganda.ò
- ñWhen robotics is implemented in the security areas of Uganda, it will reduce the use of manual labour therefore contributing to the development of the countryò

- ñIn the manufacturing industry and this will ease work and same time hence increased output and quality in production.ò

3.8 Robotics Learning Resources

In the question we investigated the adequacy of the learning resources for robotics experiments in the project-based learning approach. Some students felt the components were enough for experiments while other expressed dissatisfaction with the availability of resources for learning. The following were the views of the students:

- ñNo, we did not have enough parts, but our lecturer in this case on project was so helpfully and made sure everyone is on the same page. So hope we can be able to get enough that's if we are to move on.ò
- ñNo. We did not have enough components to develop the prototype for example we had only four wheels.ò
- ñYes I believe we had enough components for learning the basics.ò
- ñYes! I think we had most of the equipment for learning basics in robotics, since we worked with the different components at a timeò.
- ñTo a larger extent the components were enough for learning the basics in roboticsò.

4 Discussion and Conclusion

Robot construction motivates students to learn robotics science. The students are enthusiastic to see the results of their work by developing and demonstrating a physical robot. Project-based learning approach was used in the research. The students were faced with the problem of developing a rescue car robot prototype. The students designed the robot circuit, programmed the robot actions, and constructed the physical robot using the basic electronic components, arduino, motors and sensors. This project was evaluated using open-ended questions in a questionnaire. The evaluation results indicate that during the project-based learning activities, students developed skills in circuit design, robot programming, problem-solving and collaborative work. Students very much liked to extend their basic robotics knowledge to an advanced one by doing more related projects. The students also face a number of challenges that include limitations in electronic devices for robot construction, limited programming expertise, and limited time for robotics learning since it was not a regular course on the teaching timetable. There is need to promote robotics education in universities. Institutions should invest in robotics hardware and skills development. Contextualized robots have not been developed to address

variety of problems in Uganda in the areas of health, agriculture, education, tourism, fishing, climate change, floods and landslides. Little research has been done on the use of robots for development.

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