A Framework to Teach Middle School Students Mathematics and Science Using Robots

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***Abstract*— Robots have evolved in the last three decades to become a major educational tool. Many relevant organizations and competitions and academic conferences have emerged. However, schools still use robots mainly in extracurricular activities and competitions.**

Robots intrigue students by nature and increase their interest in studying. In addition, some educational robots such as Lego Mindstorms® have the feature of data logging that enables the learner to perform scientific experiments while monitoring and analyzing phenomena as long as suitable sensors are available. Examples of target areas include environmental studies, biology, physics, space exploration, etc. Such educational robot has the ability to record data from different sensors (Gyro, Ultrasonic, Color, Light, Temperature, PH, Force …) and then analyze the data or present it in various ways. This feature enables learners to perform multitude scientific experiments.

This paper proposes a framework to use robots in the classroom as a tool to teach mathematics and science concepts for eighth grade students. The framework includes science and mathematics, specifically developed, robotics-learning units, a monitoring tool to assess the implementation of the learning units, in addition to recommendations related to lesson timing and organization.

The authors developed eight robotic learning units for lessons suitable to the Palestinian science and mathematics books for 8th grade (14 years old students). These activities come as a part of the "Enhancing E-learning Project in the Palestinian Schools". Each unit contains a work plan, a student manual, a robot model building guide, and a robot sample program. The robot models in the units are of reasonable dimensions that can easily maneuver on the class ground during mobile activities and can easily stand on a standard class table in the case of stationary models and experiments. Electronic documentation copies of the activities are available for the interested.

The learning units employ robots as an educational tool of a scientific experiment. Students work in small groups to perform the experiment and answer the accompanying questions they receive from their teacher. The learning units utilize EV3 Lego Mindstorms®, an internationally accepted educational robot from Lego® to teach robotics, computer science, engineering, mathematics and science, and language. This robot does not require previous knowledge in engineering or programming. Furthermore, the authors provided a building guide for the robot model and a program for the mentor/student to download to the robot so that no special knowledge is required and the full focus is on the science and mathematics concepts behind the activity.

The authors developed a monitoring tool to evaluate the implementation of the learning units in the class. The monitoring tool measures the following issues: The teachers' knowledge of educational robotics, the utilization of educational robotics according to SAMR model, cognitive lesson level, collaborative learning, meaningful learning, lesson organization and timing, achievements of lesson specific learning outcomes.

Keywords*— *Educational robot; constructivism; constructionism; STEM education, SAMR Model; Meaningful learning

I. INTRODUCTION

Robots are programmable machines that can perform different tasks. In contrast to classical machines such as air conditioners and vacuum cleaners, robots resemble humans in the sense that they include sensors for senses, main controller for the brain, and motors for the hands and legs' joints and muscles. See figure 1

Fig. 1. Robot Basic Components

This paper consists of seven sections: An Introduction, followed by a discussion of using robots in Education. Next, we analyze the robot's potential as a STEM teaching tool. Section IV explains the proposed framework implemented in 12 schools from Jerusalem and Ramallah under the Belgium E-Learning Project [1]. Section V discusses a monitoring tool for evaluating the use of robots. Section VII describes the implementation of the project at the participating schools is detailed in. Finally, the paper concludes with recommendations presented in section VII.

II. ROBOTS AND EDUCATION

Papert developed the Logo programming language (Logo) at MIT in the 80's of the past century. With Logo, the student had the ability to control a "turtle" in order to perform specific tasks [2]. Later in the same decade, this virtual robot evolved into a real robot. A special controller and various sensors represent the brain and the human senses, while construction components used as the robot's body. Moving to design and

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build of real robots signaled the start of modern educational robotics.

Robots differ from other educational tools as it allows students to learn by doing. Using robots in education is different from lab experiments that are relatively short, has narrow objectives and are usually with predefined results. With robots, students use different senses and actions (hear, see, speak, build, move) during the learning process.

Robotics studies employ a constructionist learning approach by nature [3]. Constructionism is a modification of the original constructivism [4]. In constructionism, the learner builds knowledge while she builds, tests, and improves the models. The models created will be mostly complex in order to solve difficult problems. Constructivism states that the learner builds knowledge while interacting with his surroundings, while constructionism specifies that the learner builds knowledge while building physical models and solving problems during the process. There are many papers discussing why robot related education fits into constructionism [5, 6]. In order to understand the evolution, from constructivism to constructionism refer to [7].

The majority of robot related curricula are activities that encourage students to think and work within a team in order to solve problems [8]. Learning happens while building specific models [9].

It is important to note that robots are modern tools that educators can employ in education. What differentiate a successful employment from another are the learning environment and the adopted curricula whether it is based on theories that reflect the nature of robots or not [10].

Using robots in education opens, the room to teach concepts that otherwise were not possible in such a unified approach. Alimisis in [10] noted that the presence of robots would improve the teaching of multidisciplinary subjects such as Science, Technology, Engineering, Mathematics, Language and Art. In addition, robots can enhance cognitive and metacognitive skills. Not to ignore the students natural interest in learning robotics [11].

For a knowledge-based economy, students need to acquire critical thinking, planning, analyzing, problem solving, decision-making, meeting deadlines, collaborative learning, design, communication skills. Despite this need, most activities in the majority of schoolbooks are predefined recipes that lead to "discovering" predefined concepts. These activities where designed earlier to match the need to produce people who can perform specific thorough scientific experiments [12].

The learner can learn about, with, and from robots [13]. Robots can be used in the learning process as a learning tool as in [14, 15, and 16], or a tutor as in [17, 18] or as a peer.

For a complete review of research, concerning robots in education refer to [19, 20, and 21].

III. Robots as a Science and Mathematics Teaching Tool

Robots intrigue students by nature and increase their interest in studying. In addition, some educational robots such as Lego Mindstorms® have the feature of data logging that enables the learner to perform scientific experiments while monitoring and analyzing phenomena as long as suitable sensors are available. Examples of target areas include environmental studies, biology, physics, space exploration, etc. Such educational robot has the ability to record data from different sensors (Gyro, Ultrasonic, Color, Light, Temperature, PH, Force …) and then analyze the data or present it in various ways. This feature enables learners to perform multitude scientific experiments.

A. Benefits of data logging through educational robotics:

- Saves time, effort, and reach places that are dangerous or difficult for the students to reach and perform the data recording automatically on the computer.
- Robots can observe numerous phenomena related to sensors' behavior. Which outperform traditional devices that monitors only one or very few phenomena
- More accurate than manual observation and data recording
- Can record data of very short or very long durations
- Saves time in routine works (recording and plotting graphs), which enables focus on critical thinking and analysis
- Enables editing, storing and transforming data
- Experiments include open ended questions that encourage scientific research

B. Limitations of educational robotics

Most of the use of robots in education, especially with young pupils, is limited to extracurricular activities whether in competitions or clubs beyond the regular class hours. This is due to the prohibitive high cost of robotic kits, the lengthy robot building and programming time, the lack of robotic activities in accordance with the official curricula. In addition to that is the lengthy robotic-based-lessons preparation time, the need for multidisciplinary skills from different areas of science, engineering and computer science, the difficulty of controlling a large class with the presence of robotic kits, and finally the lack of teachers experience and satisfactory training in this field.

IV. Proposed Lesson Structure

In order to address the issues presented in previous sections, the authors introduce a new model to employ robots in mathematics and science teaching. Within this model, students work in small groups of 2-4 students each. Every group receives a single robotic kit. The lessons' structure has five stages:

- Introduction: the teacher gives a meaning and motivation to the lesson topic and relates it to the learners' real lives. The teacher can motivate the learners using visuals followed by open discussions
- Model build: the students build the model with or without instructions. Students can use computer aided design programs
- Experiment: the students perform the experiments as instructed
- Analysis and discussion: the teacher runs a discussion about the models built, the data collected, the knowledge acquired and the relationship with reality
- Conclusion: the teacher concludes the lesson with student findings and final evaluation

The authors developed eight robotic activities for lessons suitable to the Palestinian science and mathematics books for 8th grade (14 years old students). These activities come as a part of the "Enhancing E-learning Project in the Palestinian Schools" [1]. Each activity contains a work plan, a student manual, a robot model building guide, and a robot software program. The robot models in the activities are of reasonable dimensions that can easily maneuver on the class ground during mobile activities and can easily stand on a standard class table in the case of stationary models and experiments. Electronic copies of the learning units are available for the interested[1].

These activities employ robots as an educational tool of a scientific experiment. Students work in small groups to perform the experiments and answer the accompanying questions they receive from their teacher. The activities utilize EV3 Lego Mindstorms®, an internationally accepted educational robot from Lego® to teach robotics [22], computer science [23], engineering [24], mathematics and science [16], and language [25]. This robot does not require previous knowledge in engineering or programming. Furthermore, the researchers provided a building guide, and an experiment software program that is available to download to the robot, so that the students focus on the science and mathematics concepts behind the activity. Table 1 lists the developed robotic learning units.

TABLE I. SCIENCE AND MATHEMATICS ROBOTIC ACTIVITIES

Number	Activity Name	Topic/Unit
1	The triangle	Mathematics/Engineering
2	Measures of central moment (Mean, Median, Mode)	Mathematics/Statistics
3	Relative frequency and probability	Mathematics/Probability
4	The quadrilateral	Mathematics/Engineering
5	Solutions solubility	Science/Chemical Reactions
6	The division of solutions to acids and basis	Science/Chemical Reactions
7	Sound intensity	Science/Wave motion and sound
8	Light intensity	Science/Light and Optics

[1] This is an electronic reference of one unit; more learning units are available upon request. https://goo.gl/MK0yIr

A. Activities Analysis

- The activities described here attempt to harness new experiment of employing technology for science and technology studies. It is important to measure its impact on students learning
- The planning part of the activities follows standard planning guidelines
- The online content of the activities is from the United Nations Relief and Welfare association channel on YouTube [26]. This content is originally created to support the official curricula
- The mathematics activities are about the triangle, measures of central moment in probability, and the quadrilateral
- The science activities are about solutions, sound and light intensity
- Each activity contains: a plan, student manual, model building guide and a software program for the robot
- The suggested implementation duration is 90 minutes
- The activities uses the standard textbook evaluation
- The activities do not cover completely the learning unit. However, they provide learning by doing modules that enhances the learning process
- The authors suggest the implementation of the activities as they appear in the textbook

V. EVALUATION

The authors developed a monitoring tool to evaluate the implementation of the activities in the class. The monitoring tool includes elements for an effective use of educational robotics. These elements are:

- The teachers knowledge about educational robotics and their ability to employ it in the learning process
- The utilization of educational robotics according to SAMR model [27]
- Cognitive lesson level according to bloom taxonomy [28]
- Collaborative learning
- Meaningful learning [29]
- Lesson organization and timing
- The achievement of lesson specific learning outcomes
- The Impact of robotics on the goals achievement
- The evaluation of students

Table 2 presents four degrees of achievements for each topic: Unsatisfactory for poor achievements, basic for fundamental achievements, proficient for superior achievements, and distinguished for respected achievements.

TABLE II. LESSON EVALUATION RUBRIC

Topic	Unsatisfactory	Basic	Proficient	Distinguished
Teacher knowledge and skill in educational robotics	Not enough knowledge	Some knowledge yet no experience in employing robots	Enough knowledge with a need of supervision	Enough technical and pedagogical knowledge to utilize robots in teaching
Utilization of robots (SAMR model)	Robots only substitute older technology	Robots add to the learning process without modifying it	Robots modify the learning process	Robots enable the learner to experience things that were not possible with older technology
Cognitive level (bloom taxonomy)	Remember	Understand	Apply	Analyze - evaluate - create
Collaborative learning	Teacher only implements the activity	Students are allowed to participate with no collaboration or utilizing educational robots potential	Students work in groups to achieve goals	Students collaborate in groups using the manual, they analyze, discuss and communicate conclusions
Meaningful learning	Information recall with no connection to reality	No meaning or practical application	Close to the student world, a real case	There is a connection with previous knowledge and acquiring new knowledge
Lesson organization	No lesson organization	Lesson is made from stages, yet no implementation	Lesson is made from stages, yet no proper timing	Lesson is divided into stages with adequate timing
Learning outcomes	No instructions of the learning outcomes	General instructions of the outcomes	Clear and specific instructions and suitable for the learning outcomes	There is room for individual skills and abilities
Impact of robots	Robots hindered the learning process	No addition or benefit	Robots were fun, yet not direct benefit to the learning outcomes	Robots directly benefitted the achievement of learning outcomes
Students Evaluation	No criteria for evaluation	The evaluation criteria is not clear	The evaluation criteria is clear	The evaluation criteria includes formative and final elements

VI. IMPLEMENTATION

The authors developed the robotics learning units as part of the "Enhancing eLearning in Palestinian schools project" during the summer of 2015 [1]. Following the completion of these learning units, a twenty hours training course was designed and implemented. The group that participated in the training course included twenty four teachers from the fields of mathematics, science and technology, from twelve schools spanned across Jerusalem and Ramallah. Nine of the teachers teach information technology, five teach mathematics and ten teach science. Ten more supervision staff from the directorates of education from Nablus, Jenin and Hebron attended the training sessions. The training course introduced LEGO® robotics to the teachers and proposed the learning units to them. The last part of the training process included one-on-one sessions with the schools teachers. In these sessions the teachers got help with developing a custom implementation plan for every school. In November 2015, the main researcher performed follow up visits to six schools in Jerusalem. Upon teachers requests, another ten hours training course followed the previous one in December 2015. Later, the authors designed a questionnaire to assess the whole program and interviewed the participating teachers by the end of the school year.

The questions were about (a) teachers information (Age group, qualification and experience), (b) the training and the developed activities (quality, clarity, shortcomings and advantages), (c) the implementation of the activities within the school and the class (such as: students interaction, students interest in the new teaching method, whether the new method affected the understanding of the mathematics and science concepts), (d) general feedback, and finally (e) an assessment of the overall experiment.

The main researcher interviewed twelve teachers. The majority of the interviewed teachers demanded more training, specially in relation to robots programming. Most of the teachers found the robotics activities helpful and well formed. Most teachers suggest that using robotics makes teaching mathematics and science enjoyable. However, with few exceptions most schools still use robots only to teach information technology and in extracurricular activities. Half of the interviewed teachers did implement the developed activities in the class with the students. Teachers who implemented the learning units requested more time/sessions per learning unit and noted that it was difficult for a mathematics or a science teacher to implement the robotics activities alone. Five teachers agreed that students are now more interested in mathematics and science because of robots, the rest of teachers are not sure about that. Half the teachers saw general improvement in the students technical and non technical skills. These same teachers recommend robotics programs to continue. The other half of the teachers are simply not sure about the impact of robots.

VII. RECOMMENDATIONS

Robots are mainly employed in extracurricular activities for many reasons; one is the dramatic changes needed to the class structure and the classical view dominant in school education. This paper comes as part of a project that encourages the utilization of educational robotics in science and mathematics teaching. Most teachers aggree to the advantage of using robotics in education, robots intrigue students by nature. Currently, information technology teachers can utilize robotics during classes and in extracurricular activities. However, mathematics and science teachers are not confident enough to implement learning units employing robots with their students.

They require in school support and prefer joint sessions with the information teachnology teachers.

Therefore, researchers, educators and teachers need to invest more time and efforts to develop ways and activities in order to employ robots into education. In addition, more quantitative results are needed to examine the actual impact of robots on students' performance in major subjects including mathematics and science.

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