Advances in the Use of Educational Robots in Project-Based Teaching

Robertas Damaševičius [1], Lina Narbutaitė [1], Ignas Plauska [1], Tomas Blažauskas [1]

Department of Software Engineering, Kaunas University of Technology, Kaunas, Lithuania

***Abstract* – Educational robots can serve as smart, mobile and tangible learning objects which can explicitly represent knowledge through actions and engage students through immersion and instant feedback. As pedagogical background, we employ the elements of Norman's foundational theory of action and the Internet-of-Things Supported Collaborative Learning (IoTSCL) paradigm, which is based on constructivism. We describe the application of educational robots in project-based teaching at the university course. Positive relationship between successful implementation of robotics project and assimilation of theoretical knowledge has been established.**

***Keywords* – Educational robotics, collaborative project-based learning.**

1. Introduction

Recent achievements in educational robotics provide new opportunities for increasing attractiveness of Science, technology, engineering, and mathematics (STEM) education and increasing engagement of students in the study process [1]. However, any technological advance still must be matched by additional efforts (both methodological and pedagogical) to construct learning environments and develop attractive study materials [2]. The difficulties are matched by the complexity of the robotics domain itself, which includes both hardware and software parts and requires extensive knowledge of robot programming languages and environments, sensors, communication and control protocols, algorithms and artificial intelligence, as well as kinematics and mechanics.

The complexity of the robotics domain underscores the need for explicit representation and management of the semantic knowledge implicitly expressed in the educational robotics domain. This knowledge can be represented using an ontology, which is a formal data model expressed in a computer understandable form that aims to provide an exhaustive classification of entities and their relationships in a domain [3]. A comprehensive ontology of educational robotics would contribute extensively towards systematization of knowledge in this domain and enable the development of further educational tools using this knowledge [4], however, there are only nascent efforts towards the creation of such ontologies [5, 6].

The theoretical background for the application of robots in education is the Norman's foundational theory of action [7], which states seven stages of activity from its conception to formation: 1) establish a goal, 2) form an intention, 3) specify an action sequence, 4) execute an action, 5) perceive the system state, 6) interpret the state, and 7) evaluate the state with respect to the formulated goals and intentions. Another theoretical concept is immersive learning, which is based around networking [8].

In [9], we have presented a vision of using educational robots as smart mobile components (learning objects). The robot can serve as the educational service that allows to explicitly represent knowledge through actions and engage students engagement through immersion and instant feedback. In this paper, we demonstrate the implementation of the paradigm in the project-based setting at the university course.

The structure of the remaining parts of the paper is as follows. Section 2 discusses the pedagogical backgrounds. Section 3 presents case study application of the discussed ideas in the university course. Section 4 evaluates and discusses results. Finally, Section 5 presents conclusions.

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Corresponding author: Robertas Damaševičius, Department of Software Engineering, Kaunas University of Technology, Kaunas, Lithuania
Email: robertas.damasevicius@ktu.lt

2. Pedagogical backgrounds

The pedagogical background is the Internet-of-Things Supported Collaborative Learning (IoTSCL) paradigm [9], which is based on constructivism. The aims of IoTSCL is to provide a motivating learning environment in the context of university-level education, by promoting collaboration among students, and create new knowledge in a reflexive process as a result of learning-by-doing [10].

Conceptually, the role of robots in the educational CSCL environment is Robot as Learning Object (RaLO), which extends the notion of an LO beyond the virtual domain (learning content) to a physical domain (robot hardware and actions in real-world environment) [11, 12, 13].

When conceiving and implementing a project idea, the teacher directs the students towards following the methodology proposed by Uschold & Gruninger [14], which consists of a brainstorming session to identify interesting ideas to be implemented; organizing students teams based on their interest in a proposed idea, and refinement to refine the content of groups and start working. An important part of the educational setting is the introduction of elements of gamification [15] as several project teams work on the similar task thus introducing an element of competition between the teams.

Kuipers [16] identified the following levels of the robotics domain, which constitute an ontology: topological level (the categories of places, paths and regions), temporal level (time, period), causal level (views, actions, events and the causal relations among them), control level, sensory level, and metrical level (units of measurement), where each level has its own sub-ontology of concepts and problem-solving methods. In our case, the development of robotic application is based on the core concepts of Robot Programming Domain Ontology [6], which defines the robot and its environment. The "Robot" concept is a subclass of "SmartThing", which is a subclass of "PhysicalThing". This hierarchy helps to separate the properties of a robot as a "thing", e.g., mass, shape, location, etc., from its unique properties as a smart thing (e.g., unique identification, services) and finally, a robot (e.g., means of powering, operational capabilities, degree of autonomy, sensory capabilities). Figure 1. shows visualization of Core sub-ontology.

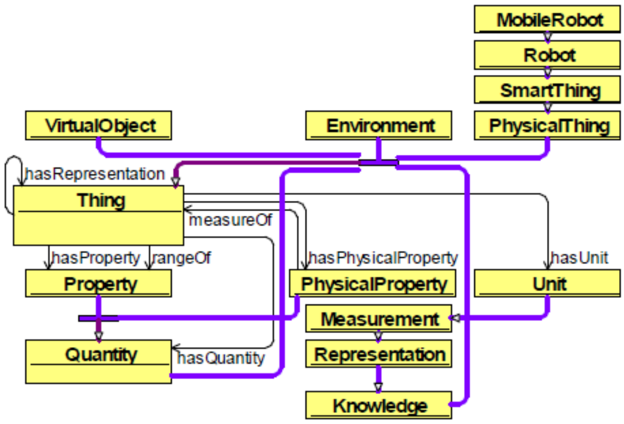

Figure 1. Core concepts in robotics domain [6]

The technological environment, referred in Figure 1., is the Computer supported collaborative learning (CSCL) in which students interact actively, share experiences and build knowledge [17]. CSCL provides a motivating learning environment, changing the learning flow and promoting collaboration among students for achieving project outcomes [18]. This real environment (as opposed to virtual learning environments common in e-learning [19]) provides students with a common problem resolution space. A robot, empowered with human-machine interface (HMI), mobility and autonomous navigation, becomes a new actor capable of interacting with the physical world and a group of students.

When drafting the requirements and tasks (or "services") for a robot, the students are encouraged to use Feature Diagrams (FDs) [20, 21], which are a convenient tool for specification, analysis and visualization of externally visible services, requirements and characteristics (formulated as features) and their relationships that a robotic system must possess and adhere to. FDs provide a view to a developed robotic system that is similar to ontology based view, but is more simple and understandable even by a non-technical person.

Another important part of the methodology are the visual robot programming languages and modelling environments such as Lego NXT and Microsoft's Visual Programming Language and V-REP, which allow for the description and understanding of complex systems, such as concurrent and/or real-time systems, for which traditional textual descriptions are inadequate [22].

The systematic application of sound pedagogical principles also requires the application of empirical analysis and knowledge modelling methods to analyse student assessment and results and feedback in order to establish any links between methods used and student results [23, 24].

3. Case study

The use of educational robots in the educational CSCL environment was explored during the practical classes of "Robot Programming Technologies", a course delivered at Faculty of Informatics, Kaunas University of Technology (Lithuania) to the 4th year bachelor students of Software Systems study programme. The course was attended by 52 students in 2014, 87 students in 2015, and 91 student in 2016. This case study is a continuation of a previous case study described in [9]

The course aims to teach students of the basic principles of robot programming and control. The main concepts to learn are the state of the robot, action/reaction (change of the state of the robot due to external or internal factors), behaviour (specific sequence of actions aimed to achieve a pre-set objective), decision (ability to undertake a specific sequence of actions from a set of alternatives), communication (ability to send/receive messages from external devices), and autonomy (ability to function independently).

This case study describes the development of one project in the group project-based educational setting. Following the Norman's foundational theory of action [7], the goal of the project has been formulated as development of algorithms for the solution of one of the classical robot programming tasks (line following, wall following, roaming, obstacle avoidance, etc.).

Some robots used in the projects are presented in Figure 2. (we mainly use Arduino and Lego).

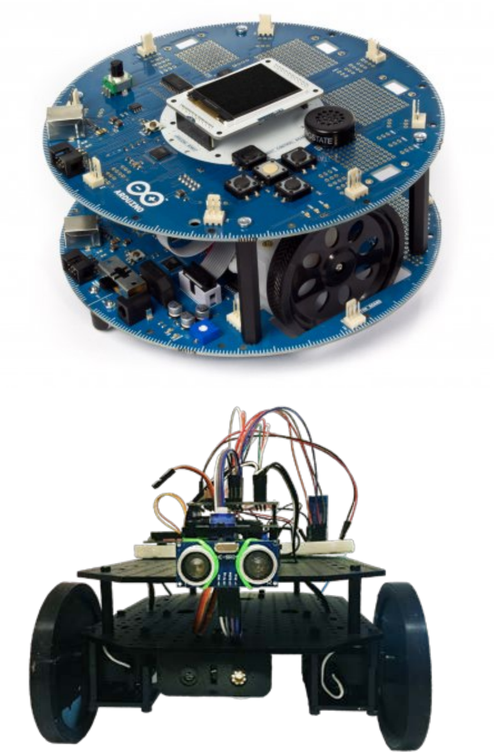

Figure 2. Examples of robots used: Arduino and Lego

In the research part of projects for evaluation robot performance, student groups used two types of experiments: physical (Arduino robot) and virtual (simulator V-REP). Using Arduino robot, the main objective was to find what is the dependence between the robot speed and the track bypass time. All experiments were performed using a test base (see Figure 3.) that was custom made to suit the purpose of this research.

Figure 3. The experiment track

The students were instructed to repeat the experiment several times (at least 3) at different robot speeds and calculate the average time. An example of the experiment results are presented in Figure 4.

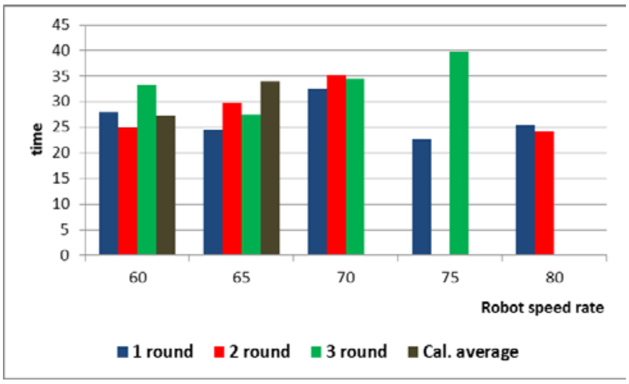

Figure 4. Track bypass time versus robot speed

Similarly, the virtual project has included development of an algorithm for a virtual robot and simulation of its behaviour on a virtual track (Figure 5.).

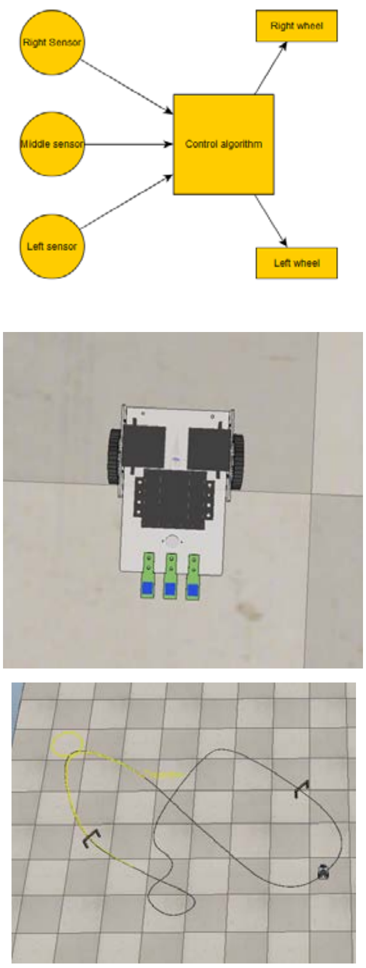

Figure 5. Algorithm, virtual robot and his track in V-REP simulator

An example of the results of an experiment performed by student groups in analysing the behaviour of 6 different robot control algorithms is presented in Figure 6.

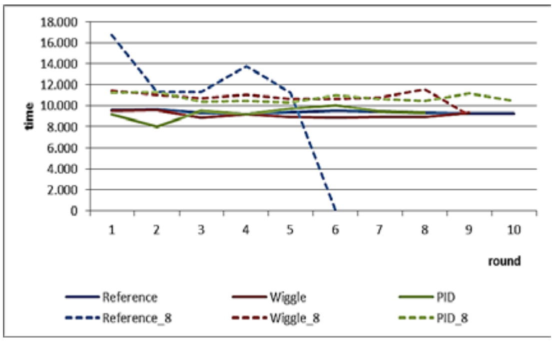

Figure 6. Results of virtual robot simulation

Finally, we have compared the results of applying our project-based teaching methods using the scores (semester project and theoretical exam) of students in academic years 2015 and 2016, which are represented in Figure 7.

Since the student evaluation data is discrete, instead we have analysed the probability distribution functions (PDF) of both data, which were calculated assuming normal distribution of data. The correlation analysis shows that there is an excellent correlation (r^2=0.94 for 2015; r^2=0.96 for 2016) meaning that both data sets statistically are very similar (see Figure 8.).

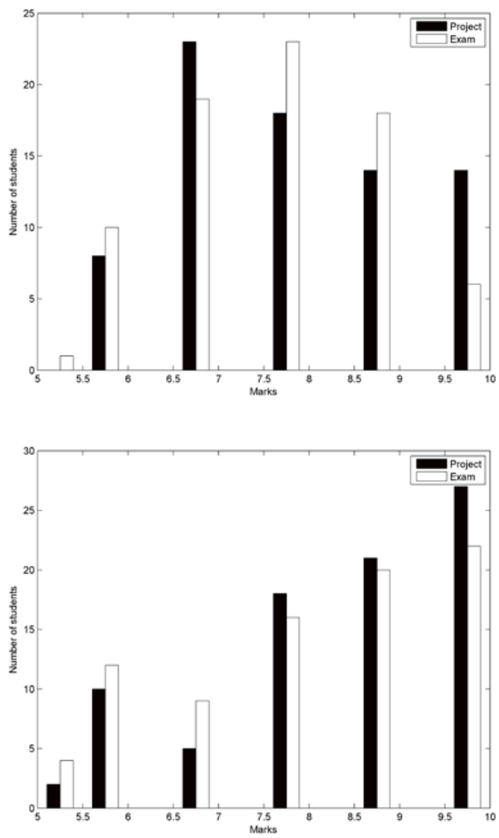

Figure 7. Student evaluations in year 2015 and 2016.

A high correlation does not necessarily imply that there is good agreement between the two sets of data. Therefore, to analyse the relationship between the PDFs of student scores of project (practical knowledge) and exam (theoretical knowledge), we used a Bland–Altman plot, which is a method of data plotting used in analysing the agreement between two sets of data. The results both for year 2015 and year 2016 (Figure 8.) show that there is a high correlation between project and theoretical exam evaluations, while agreement is within 1.96*std limits of agreement (LOA) (reproducibility coefficient, RPC=68% for 2015 and RPC=54% for 2016). The limits of agreement (LoA) are defined as the mean difference ± 1.96 SD of differences. If these limits do not exceed the maximum allowed difference between two data sets, both can be considered to be in agreement and may be used interchangeably.

Therefore, the results of the project work contribute significantly towards assimilation of theoretical knowledge of robot programming and successful passing of the course exam.

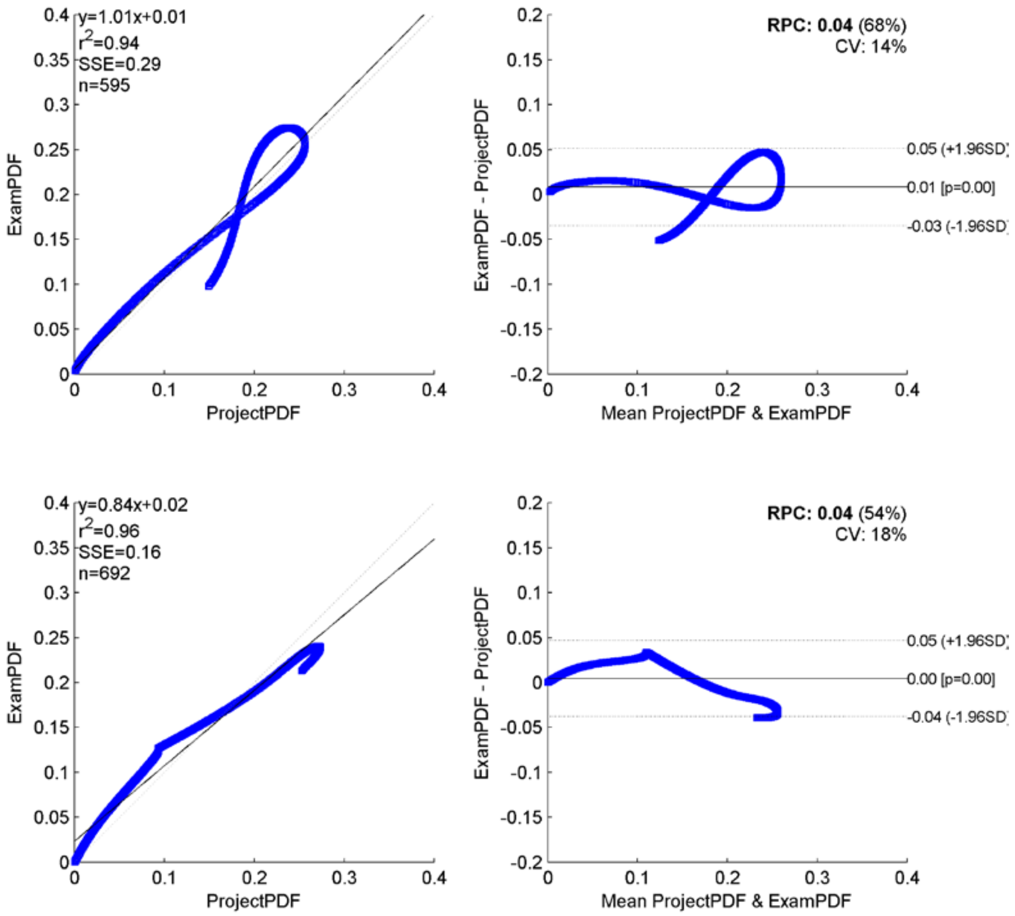

Figure 8. Correlation (left) and Bland–Altman plot (right) for the 2015 (top) and 2016 (bottom) year data.

4. Evaluation and discussion

Connecting learning services and materials to tangible objects enriched with sensors can be considered as a next generation of LOs, beyond traditional LOs, generative LOs (GLOs) [25, 26] and auto-generative LOs (AGLOs) [27]. The main contribution for education is as follows:

1) Providing contextualised learning by embedding technology (gadgets, devices, etc.) in the natural environment and personalizing learning content with respect to the learner's context and reflection [28].

2) Achieving immersion of learners, where the learner rather than interacting with the outside learning environment, actually is inside of the learning environment, with robots surrounding him.

3) Increasing student engagement by using tangible rather than virtual things. A physical thing provides immediate feedback that helps the student to acquire knowledge, correct the errors, and stimulate algorithmic thinking [29].

Challenges: the number of students attending the course has increased over the years so did the number of project groups, which brought the issue of effective management of a large number of group projects.

5. Conclusion

This paper has studied and analyzed the theoretical backgrounds and experience of implementing the robot as a mobile physical smart learning object. Such robotic learning objects can create contextualized learning ecosystems that enhance both learning outcomes and motivational states of students. The paper has discussed the experience of using a mobile robot development semester projects for combining hardware and software related subjects in context of a university course, in which students interacted with a robot as a learning object. As a result, the students acquired problem-oriented skills (knowledge and competences) in development of hardware-software systems and have developed long-term cognitive interest into the subject of study.

The use of robots as tangible learning objects allowed to enrich the learning experience by providing instant feedback and subsequent reflection, and achieving full immersion of learners into the robot-centered collaborative learning environment. The statistical analysis of student evaluation data shows that the successful completion of project contributed significantly to the successful passing of the course exam, meaning that, the knowledge assimilation process has been successful, too.

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