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Methodological system of educational robotics training: Systematic literature review

Sistema metodológico de formación educativa en robótica: Revisión sistemática de la literatura

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Contents

ABSTRACT:
The study aims to present a systematic review of the literature on the methods of teaching robotics to describe the generalized methodological system of robotics training. The findings of the literature review have been considered regarding the application of a generalized methodological system to the design of educational technologies in robotics, which makes the information resented in the paper relevant to teachers and researchers working in the field of robotics training.
Keywords: educational technology, teaching methods, educational robotics, methodological system

RESUMEN:
El estudio tiene como objetivo presentar una revisión sistemática de la literatura sobre los métodos de enseñanza de la robótica para describir el sistema metodológico generalizado de la formación en robótica. Los hallazgos de la revisión de la literatura han sido considerados con respecto a la aplicación de un sistema metodológico generalizado al diseño de tecnologías educativas en robótica, lo que hace que la información resentida en el documento sea relevante para docentes e investigadores que trabajan en el campo de la formación en robótica.
Palabras clave: tecnología educativa, métodos de enseñanza, robótica educativa, sistema metodológico

1. Introduction

Educational robotics of Central Asia has recently drawn a closer attention of researchers due to the development of a modern learning environment, which was achieved by robotic tools. In addition to this, one may witness actively developing teaching methodology aimed at increasing the effectiveness of robotics training. Theorists of educational robotics, for example, Alimisis (2009) believe that teaching robotics, a subject with certain specifics, requires a special approach that should be based on the principle of constructionism. At present moment, there are numerous experimental studies in which authors successfully apply various methods and pedagogical approaches to teaching this subject (Alimisis et al., 2009; Nourbakhsh et al., 2005; Aufderheide et al., 2012; Cuellar et al., 2013; Jung, 2013; Al-Khalifa et al., 2014; He et al., 2014; Hassan, 2014; Scaradozzia et al., 2015; Tocháček et al. (2016); Michieletto et al. (2016); Nurbekova, Mukhamediyeva et al. al (2016), Pina and Ciriza, (2017), Filippov et al. (2017), Majherová and Králík (2017).

Educational robotics was first introduced in its informal form in schools and universities of Kazakhstan in 2015. Teachers began searching for effective methods of teaching robotics, which explains the relevance of the concept "methodology of teaching robotics". A primary analysis of publications showed that this concept has not been studied in detail.

Pedagogical theory has many concepts that describe the tactics of teaching a subject. Such concepts include "Methods and Tools", "Educational Technology", "Instructional Technology", "Instructional Methods", "Educational Approach" which focus on this or that aspect of the learning process (AECT, 1977; AECT, 2004; Alessi, Stephen & Trollop, Stanley, 2001; Anderson, 2003; Collins, 1992, Seels & Richey, 1994).

Some authors (Pyshkalo, 1975; Kuzmina, 2002; Archangelski, 1980) use the concept of "methodological learning system" which consists of interrelated elements: learning objectives and content, methods, teaching forms and tools, and grading. Because the methodological system of teaching has a clear structure determined by external and internal factors, it could be easily applied and adapted in practice (Pyshkalo, 1975; Kuzmina, 2002; Archangelski, 1980). The primary analysis of the experience of teaching robotics showed that the authors do not clearly identify interrelations of elements in the methodological training system and describe only certain methods and techniques used for teaching robotics or its individual parts. This, in turn, raises the question: What is the methodological system of robotics training like?

This study aims to review systematically the publications describing the experience of teaching robotics and includes the following stages:

1) to outline the methodological system of teaching robotics for different stages of education according to the analysis of the empirical data;

2) to synthesize the considered data in a methodological system of robotics training;

3) to determine the directions for further research on robotics training.

The article consists of four sections. The relevance of the researched issues is discussed in the introduction. The second section presents the research methods and is followed by a review. The findings of the systematic literature review are given in the third section. The last section contains the general findings of the study.

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2. Research methodology and design

Systematic search and review of literature is a method described by Kitchenham (Kitchenham and Charters (2007)) and it allowed us to evaluate and interpret the available and accessible publications on the issues under study. Establishing these, we carried out a systematic analysis of the academic papers on the research theme.

Besides, we studied similar systematic reviews on the application of robotics in education done by researchers headed by Fabiane Barreto Vavassori Benitti (Benitti, 2012; Spolaôr, Benitti, 2017). These works consider educational robotics based on theories of teaching and its application in higher education.

According to Kitchenham's method of systematic analysis (Kitchenham 2004), to analyze the development of the methodological system in robotics, it is necessary to answer the following questions:

A) What is the goal of robotics training?

B) What is the content of the courses on robotics?

C) What methods, means, and forms of training are the most effective?

D) How are the learning outcomes of robotics training evaluated?

In this study, the authors analyzed over 277 publications. These articles were found in digital libraries such as IEEE Xplore and ACM, ScienceDirect, Web of science, Thomson Reuters, Elsevier, Scopus and Springer. The search field included the following keywords: "Educational Technology" OR "Instructional Technology" OR "Educational Approach" OR "Competence in Education") AND ("Educational Robotics" OR "Methodology of Educational Robotics" OR "Teaching Methods of Educational Robotics" OR "Methodical system of Educational Robotics".

Thus, when reviewing the literature, we considered 277 sources, selecting 75 out of these. Next, we carried out a qualitative analysis of 75 studies to classify the main findings. Since the study aims to identify the methodological system of robotics training, the qualitative synthesis implied extracting data from the study: the purpose of using educational robotics in the learning process, the age level of students, content, methods and tools of learning and evaluating learning outcomes. We applied the approach "from particulars to generals" (bottom up), taking into account explicit characteristics and scenarios of these studies.

3. Results

In accordance with the research, we analyzed the publications after five parameters: instructional goal, content, methodology of teaching, and evaluation of learning outcomes of robotics training. Qualitative analysis was based on 12 sources. Most authors use a Lego robotic platform in their studies. In some papers (He et al., 2014; Majherová and Králík, 2017; Michieletto et al., 2016; Jung, 2013; Aufderheide et al., 2012; Nourbakhsh et al., 2005), it was difficult to identify the elements of the methodological system as they were not explicitly stated. Nevertheless, using the descriptive information, we managed to formalize and group the studies in accordance with the elements of the generalized methodological system used for robotics training (Table 1).

Table 1 classifies the elements of the methodological system depending on their application at a certain level of training (school or higher education).

Table 1
Generalized methodological system of robotics training

Element	Primary, secondary, high school	Higher education
Goal	Building and programming robots (Alimisis et al. (2009); Cuellar et al. (2013); Filipov (2013); He et al. (2014); Hassan (2014); Scaradozzia et al. (2015); Nurbekova, Mukhamediyeva and et al. (2016); Tocháček et al. (2016);Sergey A. Filippov et al. (2017); Majherová and Králík (2017))	Computer programming and engineering (Nourbakhsh et al. (2005); Aufderheide et al. (2012); Jung (2013); H. Hassan (2014); He et al. (2014); Al-Khalifa1 et al. (2014); Michieletto et al. (2016); Filippov et al. (2017)).
	Programming and making electronics (Cuellar et al. (2013); Pina and Ciriza (2017); Filippov et al. (2017))	STEM-Education (Alimisis et al. (2009); Nurbekova, Mukhamediyeva and et al. (2016); Pina and Ciriza (2017))

	Training students for the secondary level of education. (Scaradozzia et al. (2015); Pina and Ciriza (2017))	Bridging the educational gap between academia and high school students in the field of programming (Al-Khalifa1 et al. (2014))
Content	Introductory course with LEGO MINDSTORMS: - Computer Science; - Mobile Robotics; - Embedded Design; - Software Engineering; - Sensors; - Signal Processing. (Aufderheide et al. (2012); Scaradozzia et al. (2015))	- The main concepts of robotics - Building robotics - Robots models - The EV3/ NXT programming environment - EV3/ NXT programming - Programming in RobotC - Algorithms management - Robot tasks - Application of robotics in students' major area of study (Filipov (2013); Hassan (2014); Al-Khalifa1 et al. (2014); Nurbekova, Mukhamediyeva and et al. (2016); Tocháček et al. (2016))
	• Introduction • Didactic contract • Robotics as a learning object • Theoretical framework • Methodology for developing robotics projects • Presentation and evaluation of students' projects • Course evaluation (Alimisis et al. (2009);Tocháček et al. (2016); Pina and Ciriza (2017))	• Introduction to robots • Coordinate transforms • D-H parameters • DC motor control • Motion kinematics. Robomotor Laboratory • Mobile robot kinematics. Recess for midterm. • Dynamical systems. Humanoid robot programming. • Lagrange formulation. LEGO Line tracer. • Trajectory planning. Mobile robot demonstration. • Control systems. Building Boxing robot • Robot control. Project demonstration. Project demonstration(Jung (2013))
	Content of the Programming of a Robot course: • Robotic kits, software tools • NXT-G environment • Bricx environment • Construction of robot • ROBOTC language. RVW virtual laboratory • Tutorials and instructions (Majherová and Králík (2017))	• Mobile robot tasks (Advanced line following tasks. Line following with intersections and batons). • Manipulators. • Robotics projects (Robot Greta plays hand clapping game) (Michieletto et al. (2016); Filippov et al. (2017))
Platform	Snap4Arduino, Arduino (Pina and Ciriza (2017);Filippov et al. (2017)	Lego Mindstorms Education NXT/ EV3 (Alimisis et al. (2009); Aufderheide et al. (2012); Filipov (2013); Cuellar et al. (2013); Hassan (2014); Al-Khalifa1 et al. (2014); Al-Khalifa1 et al. (2014); Scaradozzia et al. (2015); Nurbekova, Mukhamediyeva and et al. (2016); Tocháček et

		al. (2016); Filippov et al. (2017))
	Trikebot robots (Nourbakhsh et al. (2005))	IBM Robot Arm II (Hassan (2014))
	Robot Virtual World, ROBOTC (Majherová and Králík (2017))	Humanoid robotics, Raspberry Pi. (Michieletto et al. (2016); Filippov et al. (2017))
Teaching methods	Cooperative and collaborative frame of work (Alimisis et al. (2009); Jung (2013); Scaradozzia et al. (2015); Nurbekova, Mukhamediyeva and et al. (2016);Pina and Ciriza (2017))	Teamwork (Nourbakhsh et al. (2005); Alimisis et al. (2009); Jung (2013); Cuellar et al. (2013); He et al. (2014); Hassan (2014); Scaradozzia et al. (2015); Nurbekova, Mukhamediyeva and et al. (2016); Pina and Ciriza (2017);Filippov et al. (2017))
	(PrBL) Project Based Learning (Alimisis et al. (2009); D. Aufderheide et al. (2012); Hassan (2014); Al-Khalifa1 et al. (2014); Nurbekova, Mukhamediyeva and et al. (2016); Michieletto et al. (2016); Pina and Ciriza (2017); Filippov et al. (2017))	Constructionist approach (Alimisis et al. (2009); Alimisis et al. (2009); Nurbekova, Mukhamediyeva and et al. (2016); Tocháček et al. (2016); Michieletto et al. (2016); Pina and Ciriza (2017))
	Active learning (Aufderheide et al. (2012))	Gaming technology (Competition-based) (Jung (2013); J. Majherová and V. Králík (2017))
	Practical learning (Nurbekova, Mukhamediyeva and et al. (2016))	Learning of design (Nourbakhsh et al. (2005); Jung(2013); Hassan (2014))
	(PBL) Problem-based and/or Problem-solve learning (Cuellar et al. (2013); Cuellar et al. (2013); (Hassan (2014);Pina and Ciriza (2017); Filippov et al. (2017))	Self-learning through a continuous investigation or research process (Nourbakhsh et al. (2005); Pina and Ciriza (2017))
	Leadership (Cuellar et al. (2013))	Creative learning (Hassan (2014); Filippov et al. (2017))
Forms of teaching	Science clubs for schoolchildren and students (Nurbekova, Mukhamediyeva et al (2016); Pina and Ciriza (2017); Filippov et al. (2017); Majherová and Králík (2017))	Cooperation between the Professor and the student. (He et al. (2014); Tocháček et al. (2016))
	Arranging lessons on robotics in the chain “students from pedagogical university - pupils of primary, secondary school- children in kindergarten” (Nurbekova, Mukhamediyeva and et al. (2016))	Training Courses. Advanced training for teachers (Alimisisetal. (2009); Nurbekova, Mukhamediyeva et al. (2016); Tocháček et al. (2016); Pina and Ciriza (2017))
	Child works with his/her parent. (Cuellar et al. (2013))	Laboratory work (Aufderheide et al. (2012); Jung (2013); Filipov (2013); Hassan (2014); Michieletto et al. (2016); Majherová and Králík (2017))

Tools	RobotC (Aufderheide et al. (2012); Filipov (2013))	LabVIEW (Aufderheide et al. (2012); Hassan (2014); Nurbekova, Mukhamediyeva et al. (2016))
Evaluation	Pre-tests and post-tests (Hassan (2014); Al-Khalifa1 et al. (2014);Pina and Ciriza (2017))	During the course (Alimisis et al. (2009); Nurbekova, Mukhamediyeva and et al. (2016))
	Electronic portfolios (Alimisis et al. (2009))	Structured interviews (Alimisis et al. (2009))
	Individual questionnaires (Alimisis et al. (2009); Scaradozzia et al. (2015))	Feedback (Scaradozzia et al. (2015); Nurbekova, Mukhamediyeva and et al. (2016))
	Creative Robot Design (Hassan (2014); D. Scaradozzia et al. (2015); Nurbekova, Mukhamediyeva and et al. (2016))	Formative and summative (Nurbekova, Mukhamediyeva and et al. (2016))
	Competition (Filippov et al. (2017))	

The undertaken analysis shows that researchers' opinions may be classified into several groups. This indicates that, in general, teaching robotics stems from the logic of the subject domain and the platform chosen for developing robots. In addition to standard project and problem-based learning, we identified a wide variety of teaching methods used, so that the instructor has a great choice. In this regard, Competition seems to be an interesting method of evaluation (Filippov et al. (2017)) which emulates the atmosphere of the world competitions in robotics and sport excitement.

Having conducted a comprehensive analysis of the methodology of teaching robotics, we believe that the system presented in Table 1 may be seen as a generalized methodological system that teachers can use in their work.

4. Discussion

Let us consider the selected research papers regarding the questions posed in our study.

4.1. What is the goal of robotics training?

Objectives of teaching robotics are determined by the stage of education. For instance, primary and secondary school aims at teaching building and programming robots, programming and making electronics, STEM-Education. Higher education focuses on computer programming and engineering, training pupils for secondary level education, bridging the educational gap between academia and high school students in the field of programming. Learning objectives directly determine the content.

4.2. What was the content of the robotics courses?

LEGO MINDSTORMS courses include such topics as the basics of design, the environment of robots development and programming them, development of working robot prototypes for solving practical problems. Some works focus on the physical foundations of robotics. Jung (2013) adds to this list teaching programming of dynamic humanoid-like systems.

Some authors (Alimisis et al. 2009) have a special approach to robotics training as they explore teaching robotics to teachers and prospective teachers. Therefore, the course content includes didactic issues, robotics as a learning object, introduction to LEGO NXT Tan sensors, programming of mini robots, studying constructivism and constructionism in a robotics course, as well as project-based learning.

4.3. What methods, means, and forms of training are the most effective?

The authors identified the following most effective methods of robotics teaching: cooperative and collaborative frame work, teamwork, Project Based Learning, Constructionist approach, active learning, practical learning, Problem-based and/or Problem-solving learning, Leadership, Gaming technology, Learning of Design, self-learning through a continuous investigation or research process, and creative learning.

Forms of training considered by the authors include: science clubs for students and schoolchildren, cooperation between the professor and the student, arranging robotics lessons in the chain "students from pedagogical university – primary, secondary school pupils – children from kindergarten", advanced training for teachers, and children working with their parents.

The authors use special software for programming robots-RobotC and LabVIEW as a means of training.

4.4. How are the learning outcomes of robotics training evaluated?

There are numerous forms and methods for evaluating the learning outcomes of a robotics course: pre-tests and post-tests, tests during the course, electronic portfolios, structured interviews, individual questionnaires, feedback, Creative Robot Design, formative and summative evaluation. Definitely, the choice of an evaluation method depends on the level and objectives of robotics training.

Defining the elements of the generalized methodological system of robotics training enables one to structure the learning process, select elements depending on the goal and the required result of a course in robotics. Understanding interrelations of the elements in the methodological system of robotics training allows teachers to use these learning methods efficiently and to develop some elements of the methodological system by themselves.

5. Conclusion

The paper summarizes the experience of teaching educational robotics with focus on the methodological system. Thus, we considered quantitative estimates of using robots as aids in the institutions of higher education. Finally, applying the selection criteria specified in the review we chose twelve papers to synthesize the methodological system for robotics training. We analyzed the papers for the elements of the methodological system and classified them into groups.

It should be noted that the systematic literature review covered in this study was limited due to the inability to analyze sources in other languages, apart from those in English, Russian and Kazakh. Defining the research perspectives of the methods of robotics training, we studied practices of teaching this course in Kazakhstan. Thus, this article outlines new directions for further research on the methodological system of robotics training.

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