Using Collaborative Robotics as a Way to Engage Students

Lina Narbutaitė, Robertas Damaševičius, Egidijus Kazanavičius and Sanjay Misra

1 Introduction

Demand for science, technology, engineering, and mathematics (STEM) professionals is expected to grow by 8% each year until 2025 [1]. Germany, for example, is short of 210 000 workers in mathematics, computer science, natural sciences, and technology (MINT) disciplines [2]. However, there is a high-skill shortage in the STEM fields despite high unemployment rates in many countries, including European Union [3]. Many countries are suffering from low achievement and low interest among learners in STEM subjects compared to others.

STEM fields are core technological underpinnings of an advanced society and also related to the economic competitiveness of nations. Entrepreneurship, creativity, communication, and teamwork skills are needed to produce multidisciplinary scientific knowledge and innovation. However, traditionally schools and universities have struggled with the problem of embedding creativity into the STEM curriculum and attracting learners into STEM subjects. It is, therefore, important for education institutions to seek new ways to teach and grow soft skills in order to increase student interest in scientific education and technology-related careers.

L. Narbutaitė · R. Damaševičius
Department of Software Engineering, Kaunas University of Technology, Kaunas, Lithuania
e-mail: lina.narbutaite@ktu.lt

R. Damaševičius
e-mail: robertas.damasevicius@ktu.lt

E. Kazanavičius
Centre of Real Time Computer Systems, Kaunas University of Technology, Kaunas, Lithuania
e-mail: egidijus.kazanavicius@ktu.lt

S. Misra (✉)
Department of Electrical and Information Engineering, Covenant University, Ota, Nigeria
e-mail: sanjay.misra@covenantuniversity.edu.ng

S. Chakraverty et al. (eds.), *Towards Extensible and Adaptable Methods in Computing*, https://doi.org/10.1007/978-981-13-2348-5_29

The inclusion of aspects of STEM in early education provides a strong motivation as argued by the Framework on Science Education in Europe [4]. By encouraging children and young people to express themselves through the use of engineering and technology through art and design, they can be engaged more effectively than by current emphasizing of the challenge of mathematics and science skills and future benefits involved.

The STEM education curricula focus on reasoned and clear solutions to the very specific set of problems, while the curriculum of art education typically demonstrates uncertainty, ambiguity, and vagueness—an essential foundation of educational experiences focused on the development of creativity and innovation. DIY robotics, robotic toys (such as developed using the Arduino platform (https://www.arduino.cc/) can effectively serve this purpose, offering broad opportunities to showcase a practical value in different areas such as social and humanistic sciences, mainly developing student's creativity, problem solving, communication, art, media, and teamwork skills, while almost directly familiarizing with basics of physics, electronics, programming and mechanics, thus opening a broader perspective and making STEM more attractive.

Even light usage of technology having a believable and likable outcome can strongly motivate future student's perception of science and engineering education [5]. A problem of "introducing the technology" can be solved via hands-on showcases and tangible familiarization. By introducing new and familiar topics to the future students, the teacher can challenge them to work on real practical problems, make a work of art/design and by that attract them to the STEM-based topics. The design thinking implies a work methodology based on trials and iterations, i.e., the kids get to create, build, test, and evaluate solutions in iterative cycle, as well as learn to present their work to others, pitch ideas, and give critique.

The educational STEM programs implemented through robotics need the model for teaching young boys and girls who will be able to gain new skill and competences to address problems facing society. The obstacles to implement robotics as a part of formal and informal learning curriculum appear to be of the time-consuming nature of robotic activities and the need to have skilled teachers familiar with the field of robotics. The problem increases when paired with perceptions that robotics, similarly to other MST subjects, is hard, gender-biased, and not inviting for most learners [6].

In this paper, we propose and describe the educational approach, which directly aims at boosting creativity and competitiveness of schoolchildren also encouraging teachers to play a more active role in adapting innovative educational methods. The approach addresses the main problem of educational robotics; that is, most of the experiments involving robotic activities are not integrated into regular classroom activities; as they are carried out in after-school programs, or summer camps. Currently, we are not aware of any pedagogical framework nor learning scenarios aimed to design or redesign the formal education curricular based on the application of robotics in education. Therefore, a more integrative approach is required.

Here, we argue that the robots can be used not only for teaching schoolchildren and university students to learn the STEM subjects of science, technology, engineering, and mathematics, but also in social and humanistic sciences to increase the engagement of young people in technology and facilitate the acquisition of transdisciplinary knowledge. In order to be able to gain new skill, it is necessary to address real-world problems using educational robotics-based STEM courses (in a narrow sense) and STEM programmes (in a wider context) as the model. Next, we analyze the state-of-the-art approaches in educational robotics for STEM, end especially, STEAM, i.e., STEM and Arts (or all other) disciplines. The subjects of STEM and Arts, or more widely, arts, social, and humanities (AHSS), in themselves are very different by nature. Artistically oriented people operate with imagery, metaphors, and emotions, while scientists employ numbers, and formulas. Scientists are objective and artists are subjective. However, creativity allows to bridge both domains. Both social and technological skills will be very important in the twenty-first century. Robotics-enabled intercultural education (IcE) and computer science (CSE) education can facilitate multidisciplinary and multicultural projects using a low-cost, easily exported robot platform that allows students to expand their academic and personal experiences. The immediate feedback offered by robot behavior and the confidence that can help students overcome linguistic and cultural obstacles in acquiring twenty-first-century skills.

2 Pedagogical Backgrounds and Preconditions

The physical tangibility of robots raises the need for a shift to innovative and effective teaching methods for the engagement robots provide is considered conducive for learning. Schools have to be relocated at the center of the society to bring both boys and girls into the scientific world.

Engaging learners in multidisciplinary problem solving using educational robotics based on sound pedagogical framework requires academic restructuring of traditional educational models; therefore, transdisciplinary formal and informal educational STEM programs through robotics will be at the forefront of this transition.

Robot-aided learning (r-Learning) [7] has enough potential to be used as a tool of creativity in arts, humanities, and social sciences (AHSS) classes, thus attracting the attention of learners to cross-disciplinary subjects with elements of science, technology, engineering, and mathematics (STEM), where the learners can explore the combination of sculpture and robotics through the lens of art. Further on, the advantages of using robots in language instruction, known as robot-assisted language learning (RALL) [8], can be transferred to teaching other AHSS subjects. Actually spending time working with real robot-based examples gives the students many opportunities to see the topic from standpoints that are difficult or impossible to convey in a classical textbook-oriented lecture.

Discussions with industry leaders concerning characteristics to be cultivated in students suggest that they are looking for creative and innovative people (described as “thinking outside the box”), those who can work in teams with other people. Traditional STEM education based on constructionism focuses on the convergent skills, whereas social science and art focus on the divergent skills. Having the ability to execute both at scale can better position the young people of Europe for global competitiveness [9]. Educational robotics can be employed to inspire curiosity and creativity in students [10].

Robotics enables recognizing the world by trying and doing rather than by observing or listening. The main appeal arises from the potential of educational robotics to enhance student's intellectual, social, emotional, physical, and artistic development and to foster creativity and a lifelong love of learning. The way robotics is currently introduced in educational settings usually focuses just on a narrow subset of topics mainly in the field of mathematics and physics. Further on, the interrelation between science and art is also reflected, and here the term "robotic art" emerges. "Robotic art" [11] is a type of art that makes use of robotics and automated technology, coupled with computer technology and sensors. Robotic art attracted attention with the rise of electronic media and technology in art.

Despite these nascent efforts, there is lack of pedagogical scenarios and methodological background in order to use educational robotics in non-STEM classes to attract students to STEM more systematically. There has been some effort in the context of Science, Mathematics, Art, Robot, and Technology (SMART) with little emphasis on the Art part of SMART [12]. Exploring a wider range of possible applications for robotics in the context of STEAM such as poetry, history, human anatomy [13], and biology [14] can engage young people (both girls and boys) in undertaking scientific careers. The schoolchildren interested in arts, humanities, and social sciences (AHSS) still could be attracted to interdisciplinary studies (e.g., design engineering) involving a significant part of technological subjects, if properly addressed and motivated. Instead of focusing on a single technological challenge such as design of an autonomous robotic carriage for line following or obstacle avoidance, robots could be deployed in a more creative environment such as development of robotic musical instruments for music-oriented students, development of wearable art with computing capabilities for art- and design-oriented students, and creation of robotic characters for humanities-oriented students. This is why the goal is to embrace the significant potential of educational robotics for boosting problem-solving and teamwork skills [10].

It is a known fact that investment in the pure STEM fields—science, technology, engineering, and mathematics—increases innovation and supplements to the economic development, which is very important to the developing countries. The decrease in unemployment through a positive notion of social impact of robots is expected. Educational robotics also can indirectly reduce the fear of robots as an alternative workforce and increase the familiarity of technical objects. A more direct economic impact will result from schoolchildren as future workforce which generates country gross domestic product (GDP) and makes it competitive in the world's economics. Consequently, the development invites growth in new jobs in a community.

Educational robotics can introduce the design, artistic, and creative processes to informal learning through the emphasis on engineering knowledge, improving student engagement, and reducing boundaries between different disciplines, establishing a synergistic relationship. By using robots as an art form and attracting artists who include science in their artworks, the interest of not only students, but educators and researchers in STEAM disciplines can be increased. Introducing young people to hybrid works of art and technology and by offering a robot as an educational art tool, we will be able to help young people to understand more about the mix of STEM subjects with artistic/creative process, design thinking, and computational thinking [15, 16]. Robotics can alleviate the lack of interest toward STEM subjects in students and has the potential to change students' view on learning of STEM subjects [17]. The hands-on, imaginative approaches to science education, combining simple robotics with many of the methods used in the creative arts and design are aimed to attract and retain young people in the fields of STEM. Using educational robotics, Robotic Art can serve as a tool to facilitate STEAM learning [18]. Moreover, the value of educational robotics is in its applicability for all age groups, including kindergarten [19], schoolchildren from first grade to 12th grade [20], and university students [17], both in the formal education setting and in homeschooling environment [21].

However, the successful implementation of STEM education, however, requires the preparation of core activities [22], which in our case is the model-based design of educational robots. The methodology is described in more detail in Sect. 3.

3 Methodology

The methodology of using educational robotics in the classroom described in this paper is based on the duality of teamwork learning and collaborative robots. The approach is based on the duality between the problem domain, which in our case is the problem of team building and management of teamwork, and the application domain, where team building is implemented and explicitly visualized by collaborative interacting and communicating robots. The idea itself is not entirely new as is known in the domain of software engineering. In product line engineering (PLE), domain engineering focuses on the capture of knowledge, while application engineering reuses that knowledge for developing specific systems [23]. In agile software engineering, the dependencies between requirements and architecture have been described as the "twin peaks of requirements and architecture" [24]. The model focuses on build successful and cost-effective software systems by supporting the co-development of requirements and architecture.

Shulte [25] introduced the concept of educational lenses for the duality deconstruction of Informatics Systems for teaching ICT topics. The approach provides an example of word processor as command-based knowledge that leads to inefficient teaching model that focuses on introducing and practicing commands rather than giving the learner additional (strategic) knowledge. From the socio-technical perspective, all Information Technology (IT) artefacts are dual artefacts, which have technical structure focusing on data, algorithms, and operations, yet their function is social, which very much depends on its surrounding social context [26]. One of the outcomes of such duality is the crisp separation of developers (designers) and users of IT. While designers focus on creating new systems and products, the users are only capable of utilizing pre-given application. The results are the insider/outsider

[27] or the creator/consumer dichotomy, which in itself contributed to many misconceptions in computer science education, not the least being the notable gender gap in enrollment to computer science subjects [28].

Rethinking of the processes and concepts of IT reformulation in terms of duality [29] allow a deeper and more dialectical understanding of the interaction between technology and socium and has important implications for the development and use, especially for teaching of IT and computer science topics. The ability to understand and strengthen specific patterns of human behavior [30], which are recurring across different types of systems and domains can ease the steep learning curve of modern IT and computer science.

The development of complex modern IT systems such as multi-agent systems, artificial neural networks (ANNs), bio-inspired algorithms, or swarm robotics encounters nowadays a real challenge. Nethertheless, the similarity of such systems to real-world living systems or social networks provides an inspiration for better understanding of both technical systems and their real-world counterparts. Conceptualization of social processes and forces in terms of explicitly visible and physically tangible objects such as collaborating education robots allows to better understand their principles of function as well as to overcome the mechanistic view on technical systems as closed ones [31]. The approach also can contribute toward developing and enhancing non-technical skills of students in IT education [32].

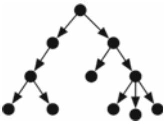
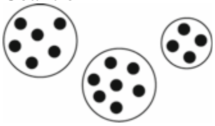
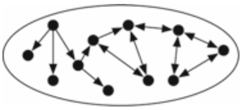
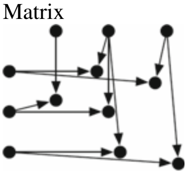
Systematic production of graduates who have critical skills of teamwork and team management and are employable in modern global workplace is a challenge to IT education. Practical knowledge and experience are essential to the formation of teams [32]. Effective deliverance of such knowledge and skills requires rethinking of traditional teaching and learning methods. The results of the study [33] show that the practice activities performed in cooperation had improved group performance and behaviors. The idea to apply project-based collaborative approach to educational robotics is not new and has been successfully applied elsewhere (see, e.g., [34]).

Following Hagen and Bouchard [32], the implementation of the simulated project with inclusive training of non-technical skills can be implemented in a four-step instructional process:

- Concept–Problem Identification: The students identify the technical problem and its dual social counterpart
- Cognitive reframing of problems to find viable solutions
- Implementation, which includes both traditional technical process of software programming and hardware assembly as well as social relationship building
- Evaluation and self-assessment both in terms of technical characteristics of created product and ore wider context of soft skills (communication, collaboration, team management, including conflict management) acquired.

Moreover, our methodology is based on the next-generation science standards (NGSS) framework practices [35] as follows: (1) asking questions and defining problems, (2) developing and deploying models, (3) planning and performing experiments, (4) analyzing and explaining data, (5) engaging in computational thinking,

Table 1 Conceptual correspondence of between robotic and human teams

Type of Organization	Robotic teams	Human teams
Hierarchy 	A single leader has the authority to make decisions. Upper-level agents control lower-level agent	Leader (manager) assigns them sub-tasks and resources to complete the task
Coalition 	Loosely affiliated organization without a clear leader	Individual members take initiative to implement their ideas, while the burden on leaders to make every decision is reduced
Cooperative 	Agents cooperate to achieve common aim	An autonomous association of persons united voluntarily to meet their common needs
Matrix 	Agent capabilities and work commitments are shared between multiple leaders	A flat organization has few or no levels of middle management between staff and executives

(6) selecting best solutions, (7) discussing the results based on evidence, and (8) communicating the results and experience.

The domain of robotic teams is organized by applying the taxonomy of organizational paradigms in multi-agent systems presented in [36], which include hierarchy, coalition, cooperative, and matrix organizations (see Table 1). The conceptual similarity between robotic agents and humans helps to underscore the importance of teamwork in task execution. The students are introduced with the possible structure of their teams and can choose freely how to organize their team.

4 Case Study

The approach described in this paper has been adopted in Kaunas University of Technology, Faculty of Informatics. The students in the Robotics Programming Technologies Course (a part of Software Systems study programme), during 2012–2016, in total 293 students (2012–34, 2013–33, 2014–51, 2015–86, 2016–89). The course aims to teach students of the basic principles of robot programming and control using the collaborative teamwork approach [37, 38]. During 5 years, the students have implemented 89 team projects.

The robot hardware used during laboratory works included two LEGO NXT robots with NXT Intelligent Brick, Arduino 4WD Mobile Platform with ATmega328 microcontroller board, Lynxmotion 5LA Robotic Arm robotic arm with 6DOF, and a two-fingered gripper. The control was implemented using the SSC-32 protocol.

The course is based on project- and team-based approaches to teaching the principles of robotic programming. The approach involves giving students a robot to assemble, and providing increasingly complex challenges to solve, starting from simple line following to roaming in a crowded, dynamical changing environment. The use of entertaining ideas for project is encouraged as gamification plays an important role in student engagement and interest sustainment [39].

Students work on their semester assignments in groups of 3–4 students. The adopted learning scenario is as follows:

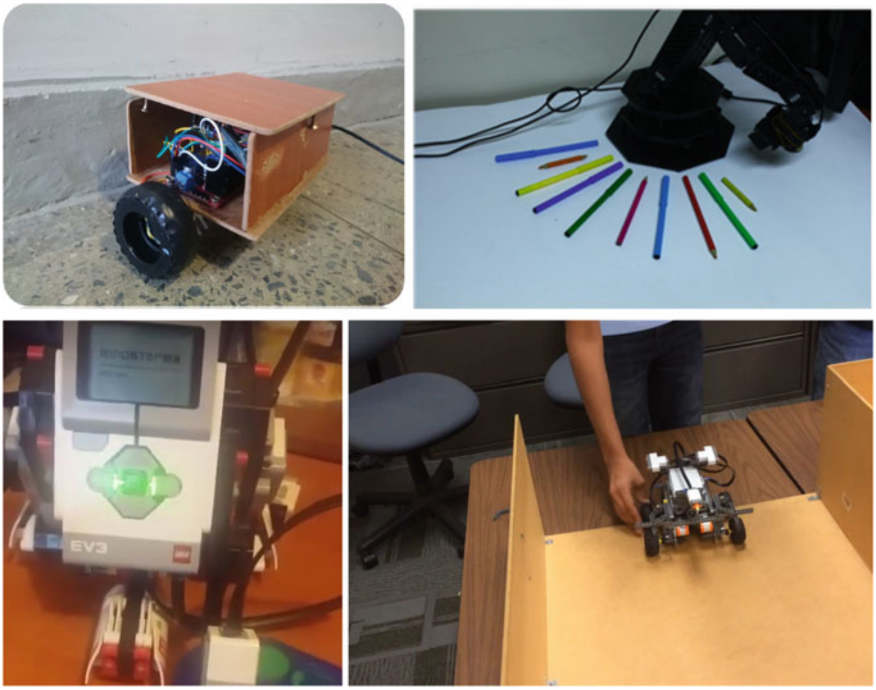


Fig. 1 Examples of implemented robotics projects

(1) A team of students are presented with a typical robotics problem (such as line following, obstacle avoidance) and materials required for solving it.
(2) The students analyze study literature and select the most appropriate solutions under the guidance of the teacher. The design and modeling of a robotic system involve the use of visual programming environments [40] such as Microsoft Robotics Developer Studio, NXT-G, or Virtual Robot Experimentation Platform (V-REP).
(3) The students construct, model, and implement a robot using the robot modeling and programming environment required to implement the task.
(4) The students empirically validate the solution by performing several experimental runs of the robot.
(5) The students present their implemented robot to other students and the teacher at the semester workshop. Presentation framed as a learning object (LO) [41–43] is encouraged; that is, the students formulate their educational aims, describe the implementation of the projects using multimedia materials (videos, photographs, diagrams), and present conclusions what they have learned. The Moodle learning platform is used as a common media to discuss projects and share learning experience.

Some of the implemented robotics projects are illustrated in Fig. 1.

5 Evaluation

After the students completed the course, they were asked to complete a self-assessment survey and evaluate their abilities before and after the course: The students were asked to evaluate their abilities before and after the course as follows:

1. Ability to model and construct typical robots using a programming, modeling, and imitation environment Virtual Robot Experimentation Platform (V-REP) and robotic platforms (Arduino, Lego).
2. Able to explain robot control architectures and apply robot control algorithms.
3. Ability to design and implement the control of a typical robot.

The survey used a five-item Likert rating corresponding to as follows: 1. Very poor; 2. Poor; 3. Neutral; 4. Good; 5. Very good. The aggregate survey ($N = 113$) results are presented in Fig. 2. The results show that students overall have improved their knowledge in the field of robot programming.

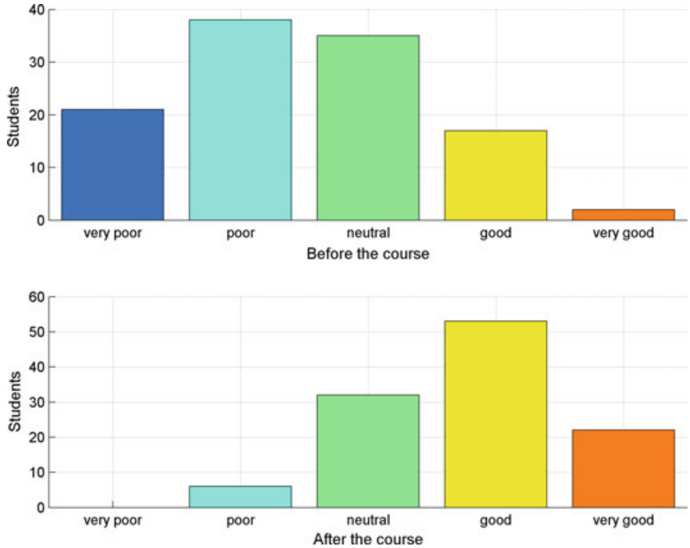


Fig. 2 Aggregated survey results before and after course completion

6 Conclusion

Educational robotics focuses on the link between physical materials of the educational actions and the virtual ones like project Web site, student and teacher online support tools (e.g., Moodle) and to cultivate creativity and problem-solving skills via easy accessible robotic do-it-yourself (DIY) experiences, looking at it not as a robot hardware, but as a virtual storyteller (such as traveler in the labyrinth) in the integrated learning environment. The use of Moodle as the robotic learning (r-Learning) environment assures the interactivity of the educational content and the effective knowledge assimilation.

Educational robotics can be used to raise awareness of the career path of young girls and boys to successfully meet STEAM (STEM + Art) challenges in the educational process and to stimulate attractiveness of science education in line with the principles in gender equality for development of innovative, creative, and sustainable societies in Europe and elsewhere. The approach is especially relevant for the developing countries such as India or Nigeria. In addition, the integrated teaching approach fosters a stronger overlapping between formal, informal, and non-formal learning to make scientific and technological as well as transdisciplinary careers attractive to young students, increasing competitiveness of young people on the job market in the future, establishing a clear link between creativity and science, and providing with critical teamwork skills.

References

1. European Commission. (2014). EU Skills Panorama. Skills challenges in Europe. Analytical Highlight.
2. Directorate general for internal policies. (2015). *Encouraging STEM studies: Labour market situation and comparison of practices targeted at young people in different member states*.
3. Dobson, I. (2013). STEM: country comparisons–Europe. In *A critical examination of existing solutions to the STEM skills shortage in comparable countries*. Melbourne: Australian Council of Learned Academies.
4. Forsthuber, B., Motiejunaite, A., & de Almeida Coutinho, A. S. (2011). *Science education in Europe: National policies, practices and research.* Education, Audiovisual and Culture Executive Agency, European Commission.
5. Flegg, J., Mallet, D., & Lupton, M. (2012). Students' perceptions of the relevance of mathematics in engineering. *International Journal of Mathematical Education in Science and Technology, 43*(6), 717–732.
6. Blikstein, P. (2013). Digital fabrication and 'making' in education: The democratization of invention. In J. Walter-Herrmann & C. Büching (Eds.), *FabLabs: Of machines, makers and inventors*. Transcript Publisher.
7. Han, J. (2010). Robot-aided learning and r-learning services. In D. Chugo (Ed.), *Human-robot interaction*, Vol. 288. Croatia: INTECH.
8. Aidinlou, N. A., Alemi, M., Farjami, F., & Makhdoumi, M. (2014). Applications of robot assisted language learning (RALL) in language learning and teaching. *International Journal of Language and Linguistics, 2*(3–1), 12–20.
9. Madden, M. E., Baxter, M., Beauchamp, H., Bouchard, K., Habermas, D., Huff, M., et al. (2013). Rethinking STEM education: An interdisciplinary STEAM curriculum. *Complex Adaptive Systems, 2013,* 541–546.
10. Zawieska, K., & Duffy, B. R. (2015). The social construction of creativity in educational robotics. *Progress in Automation, Robotics and Measuring Techniques, 2,* 329–338.
11. Kac, E. (1997). Foundation and development of robotic art. *Art Journal*, *56*(3); *Digital reflections: The dialogue of art and technology* (pp. 60–67).
12. Hong, S. Y., & Hwang, Y. H. (2012). A study on smart curriculum utilizing intelligent robot simulation. In *Issues in Information Systems, IACIS* (Vol. 13, No. 2, pp. 131–137).
13. Hamner, E., & Cross, J. (2013). Arts & bots: techniques for distributing a STEAM robotics program through K-12 classrooms. In *Proceedings of the Third IEEE Integrated STEM Education Conference*, Princeton, NJ, USA.
14. Rahman, A., Saleh, A., & Abdelbaki, N. (2017). Innovative human-robot interaction for a robot tutor in biology game. In *18th International Conference on Advanced Robotics (ICAR)* (pp. 614–619).
15. Burbaite, R., Drasute, V., & Stuikys, V. (2018). Integration of computational thinking skills in STEM-driven computer science education. In *IEEE Global Engineering Education Conference, EDUCON* (pp. 1824–1832). https://doi.org/10.1109/educon.2018.8363456.
16. Štuikys, V., Burbaite, R., Blažauskas, T., Barisas, D., & Binkis, M. (2017). Model for introducing STEM1 into high school computer science education. *International Journal of Engineering Education, 33*(5), 1684–1698.
17. Khanlari, A. (2013). Effects of educational robots on learning STEM and on students' attitude toward STEM. In *2013 IEEE 5th Conference on Engineering Education (ICEED),* Kuala Lumpur (pp. 62–66). https://doi.org/10.1109/iceed.2013.6908304.
18. Daugherty, M. K. (2013). The Prospect of an 'A' in STEM education. *The Journal of STEM Education*, 10–15.
19. Ioannou, M., & Bratitsis, T. (2017). Teaching the notion of speed in kindergarten using the sphero SPRK robot. In *IEEE 17th International Conference on Advanced Learning Technologies, ICALT 2017* (pp. 311–312). https://doi.org/10.1109/icalt.2017.70.

20. Wang W. H. (2016). A mini experiment of offering STEM education to several age groups through the use of robots. In *2016 IEEE Integrated STEM Education Conference (ISEC)* (pp. 120–127), Princeton, NJ. https://doi.org/10.1109/isecon.2016.7457516.
21. Plaza, P., Sancristobal, E., Carro, G., & Castro, M. (2017). Home-made robotic education, a new way to explore. In *2017 IEEE Global Engineering Education Conference (EDUCON)* (pp. 132–136), Athens. https://doi.org/10.1109/educon.2017.7942837.
22. Yamagata, H., & Morita, T. (2017). Design of contest for educational underwater robot for STEM: Learning applying modeling based on control engineering. *Journal of Robotics and Mechatronics, 29*(6), 957–968. https://doi.org/10.20965/jrm.2017.p0957.
23. Frakes, W. B., & Kang, K. (2007). Software reuse research: Status and future. *IEEE Transactions on Software Engineering, 31*(7), 529–536.
24. Cleland-Huang, J., Hanmer, R. S., Supakkul, S., & Mirakhorli, M. (2013). The twin peaks of requirements and architecture. *IEEE Software, 30*(2), 24–29.
25. Schulte, C. (2012). Uncovering structure behind function: The experiment as teaching method in computer science education. In *Proceedings of the 7th Workshop in Primary and Secondary Computing Education (WiPSCE '12)* (pp. 40–47). New York, NY, USA: ACM.
26. Damasevicius, R. (2009). On the human, organizational, and technical aspects of software development and analysis. In *Information systems development: Towards a service provision society* (pp. 11–19). https://doi.org/10.1007/b137171_2.
27. Crutzen, C. K. M. (2000). *Interaction, a world of differences. A vision on informatics from the perspective of gender studies*. Open Universiteit Nederland.
28. Limanauskiene, V., Rutkauskiene, D. Kersiene, V., Bareisa, E., Damasevicius, R., Maskeliunas, & R., Targamadze, A. (2017). The study of gender equality in information sciences research institutions in Lithuania. In *Information and Software Technologies, ICIST 2017*; *Communications in computer and information science* (Vol. 756, pp. 499–511). https://doi.org/10.1007/978-3-319-67642-5_42
29. Orlikowski, W. J. (1992). The duality of technology: Rethinking the concept of technology in organizations. *Organization Science, 3*(3), 398–427.
30. Di Maio, P. (2014). Towards a metamodel to support the joint optimization of socio technical systems. *Systems, 2014*(2), 273–296.
31. Katsioloudes, M. I. (1996). Socio-technical analysis: A Normative model for participatory planning. *Human Systems Management, 15,* 235–244.
32. Hagen, M., & Bouchard, D. (2016). Developing and improving student non-technical skills in IT education. *A Literature Review and Model*, *3*(7) (2016).
33. Cavalier, J. C., Klein, J. D., & Cavalier, F. J. (1995). Effects of cooperative learning on performance, attitude, and group behaviors in a technical team environment. *Educational Technology Research Development, 43,* 61–72.
34. Karaman, S., Anders, A., Boulet, M., Connor, J., Gregson, K., Guerra, W., & Vivilecchia, J. (2017). Project-based, collaborative, algorithmic robotics for high school students: Programming self-driving race cars at MIT. In *7th IEEE Integrated STEM Education Conference ISEC 2017* (pp. 195–203). https://doi.org/10.1109/isecon.2017.7910242.
35. Ziaeefard, S., Miller, M. H., Rastgaar, M., & Mahmoudian, N. (2017). Co-robotics hands-on activities: A gateway to engineering design and STEM learning. *Robotics and Autonomous Systems, 97,* 40–50. https://doi.org/10.1016/j.robot.2017.07.013.
36. Horling, B., & Lesser, V. (2004). A survey of multi-agent organizational paradigms. *Knowledge Engineering Review, 19*(4), 281–316. https://doi.org/10.1017/S0269888905000317.
37. Plauska, I., & Damasevicius, R. (2014). Educational robots for internet-of-things supported collaborative learning. In *International Conference on Information and Software Technologies, ICIST 2014.* Springer; *Communications in computer and information science* (Vol. 465, pp. 346–358). https://doi.org/10.1007/978-3-319-11958-8_28.
38. Damasevicius, R., Narbutaitė, L., Plauska, I., & Blazauskas, T. (2017). Advances in the use of educational robots in project-based teaching. *TEM Journal, 6*(2), 342–348. https://doi.org/10.18421/TEM62-20.

39. Aseriskis, D., & Damasevicius, R. (2014). Gamification patterns for gamification applications. In *6th International Conference on Intelligent Human Computer Interaction, IHCI 2014*, Évry, France, 8–10 Dec 2014; *Procedia Computer Science 39*, 83–90. https://doi.org/10.1016/j.procs.2014.11.013.
40. Plauska, I., Lukas, R., & Damasevicius, R. (2014). Reflections on using robots and visual programming environments for project-based teaching. *Elektronika ir Elektrotechnika, 20*(1), 71–74. https://doi.org/10.5755/j01.eee.20.1.6169.
41. Burbaite, R., & Stuikys, V., Damasevicius, R. (2013). Educational robots as collaborative learning objects for teaching computer science. In *IEEE International Conference on System Science and Engineering, ICSSE 2013* (pp. 211–216). https://doi.org/10.1109/icsse.2013.6614661.
42. Štuikys, V., Burbaite, R., & Damaševičius, R. (2013). Teaching of computer science topics using meta-programming-based GLOs and Lego robots. *Informatics in Education, 12*(1), 125–142.
43. Stuikys, V., Burbaite, R., Drasute, V., & Bespalova, K. (2016). Robot-oriented generative learning objects: An agent-based vision. In *10th KES International Conference on Agent and Multi-Agent Systems: Technology and Applications, KES-AMSTA*; *Smart Innovation, Systems and Technologies* (Vol. 58, pp. 247–257). Springer. https://doi.org/10.1007/978-3-319-39883-9_20