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Programming Human-Robot Interactions for Teaching Robotics within a Collaborative Learning Open Space: Robots Playing Capture the Flag Game

Programming Human-Robot Interactions within a Collaborative Learning Open Space

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ABSTRACT

Game-based competitive or cooperative robotics activities constitute an effective approach to exploit the child-robot interaction perspective. However, in most game-based robotics activities robots act autonomously to achieve the goal. In this work, we aim to promote the child-robot interaction aspect through a multiplayer game where one team of robots and humans collaborates to compete with another team of humans and cobots. We describe the design of an open space that will allow children to gain access, locally and remotely, and program robotic agents to play the traditional "Capture the Flag" game in a physical stadium-arena. Through this space, we intend to teach robotics, while programming human-robot interfaces, within a computer-supported game-based learning environment. We give insights on the initial design of such an open space and the educational benefits of its use in the comprehension of abstract computational and STEM concepts.

CCS CONCEPTS

• **Social and professional topics** → Professional topics; Computing education; Computational thinking; Professional topics; Computing education; K-12 education; Professional topics; Computing education; Computing education programs; Computer science education; • **Computer systems organization** → Embedded and cyber-physical systems; Robotics; External interfaces for robotics; • **Applied computing** → Education; Collaborative learning.

KEYWORDS

Child-robot interaction, educational robotics, children, computational thinking, game design, STEM, embodied learning

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1 INTRODUCTION

In this work, we describe the initial design of an open learning space that will allow participants to gain access and program robotic agents to play collaborative-competitive games in a physical stadium-arena. Additionally, we propose a robotics curriculum, where students will be able to explore various computational and scientific concepts as they develop human-robot interfaces for the remote control of the robotic agents.

A central purpose of child-robot interaction, a growing research subfield of human-robot interaction [Goodrich and Schultz, 2007], is to foster the learning process, whilst children engage in meaningful interactions, in real-time, with tangible computationally enhanced manipulatives that exist in the real world. Robots have been employed in education in a variety of ways and diverse pedagogical contexts. For example, educational robotics have been extensively used to support learning in Science, Technology, Engineering, and Math (STEM) [Papert, 1987]. Telepresence robots play a significant role in distance education as they can bring teachers and learners together in cases where physical presence is not available. Social robots [Belpaeme et al., 2018], by establishing a natural interaction with children, can serve the social role of robotic tutors not only in special but also in general education.

Following this trend, we embrace a hybrid approach that blends the traditional autonomous robot movement with the child-robot interaction perspective. As there is evidence that students prefer more competitive or cooperative robotics activities, such as sumo-fighting [Kim and Jeon, 2008], or football-playing [Eguchi, 2016], game-based robotic activities constitute an effective approach to exploit this synergy. However, in most game-based robotics activities, such as Robocup [Eguchi, 2016], robots act autonomously and collaboratively to achieve the goal. We intend to promote the child-robot interaction aspect through a multiplayer game where one team of robots and humans collaborates to compete with another team of humans and collaborative robots (cobots [Colgate et al., 1996]).

Additionally, educational computing activities, such as the robotics ones, not only need to motivate students' interest in the respective academic subjects but furthermore, sustain, and develop this interest [Hidi and Renninger, 2006]. Context is one of the most important factors we can use to motivate learners, and it can be effective even in more advanced computer science classes [Guzdial, 2015]. Serious games have been widely used for motivating and enhancing learning but the full potential of serious gaming can be uncovered through a game-making approach that connects the roles of players and designers [Kafai and Burke, 2015). Additionally, the addictive nature of gameplay mechanics makes serious games a useful tool in various educational fields, such as educational robotics. Especially the use of familiar and simple gameplay, such as "Capture the flag" [1] (CTF) could facilitate the infusion of serious content.

Influenced by Bret Victor's [Victor, 2014] vision on "Seeing Spaces", we similarly conceptualize an open space as a learning environment, like a workshop or maker space, for enabling understanding instead of building robots. We envision an open space that will enable a constructivist approach to teaching and learning, as participants will engage their own physicality to understand the behavior of the robot they will program and use. The open space will support students to develop various human-robot interfaces that range from pure teleoperation, and pure autonomous movement to mixed interfaces (teleoperation and autonomous) promoting peer-to-peer collaboration between humans and robots to achieve a collective goal. The robots will act as surrogate agents playing the traditional CTF game and will be accessible locally, but also from a distance, through the internet. In this way, tele-education will be promoted and educational robotics will become more approachable to students.

Through this space, we intend to teach K-12 students robotics. Thus, we also propose a robotics curriculum where students will be able to explore concepts such as computational thinking (CT), artificial intelligence, game design, kinematics, problem-solving, and STEM. We believe that a robotics curriculum can be significantly improved regarding content, cognition, and motivational interest if the activities involve game-based pedagogical approaches within a computer-supported collaborative learning (CSCL) environment that promotes child-robot interaction. In this way, educational robotics curriculums will become more meaningful to students [Alimisis, 2013].

The research questions that we will try to address with this project are:

- How can a game-based collaborative learning open space make educational robotics more approachable to children?
- Can a multiplayer game-based approach promoting child-robot interaction make robotics curriculums more meaningful and enhance the learning of abstract CT and STEM concepts?

2 METHODOLOGY

2.1 Setting

In its complete state, the proposed open space will allow participants to explore and learn robotics both locally and from a distance. Previous works have also considered the implementation of open spaces [Fernandez et al., 2007] for accessing educational robotics from a distance. However, they have not considered teaching robotics while programming human-robot interfaces for playing real-time multiplayer games within a collaborative learning open space.

By providing access via the internet, it is possible to distribute the educational material outside the academic centers, not only to programmers but also to novices who just want to explore robotics. This flexibility, also found in telepresence robots, can mitigate the loss of learning, especially in cases where the physical presence of students is not possible due to the suspension of educational activities for health safety reasons. Coronavirus pandemic threatens not just our health, societies, and economies but also has a significant impact on the educational process. On this basis, we must equip teachers and educators with the appropriate tools to be able to incorporate important skills, such as active learning, critical and CT into the classroom. More notably, students should take control of and become more responsible for their own learning [Asrifan, 2020]. Advanced technologies, such as open spaces, could provide a playful effective learning environment not only to support students to be self-motivated to learn but also change the role of the teacher from that of an information disseminator to a facilitator of learning.

Besides natural disasters and pandemics, the robotics infrastructure is quite expensive, so through this open space, we can offer a stadium-arena of robots for online booking and experimentation, supporting young learners who cannot afford the purchase of a robotic toolkit. An alternative cheaper solution would be the use of virtual robotic arenas, such as robot virtual worlds[2], but these tools are computer simulations thus students can't make use of real robots that function in real environments.

2.2 Robotics Curriculum

We intend to design and implement an educational robotics curriculum, where students are asked to develop human-robot interfaces for the remote control of tangible robots using diverse interaction styles such as touch, speech, and hand and full-body gestures [Merkouris and Chorianopoulos, 2019, Merkouris et al., 2019]. In a typical educational robotics activity, students are asked to enliven the robots by creating the appropriate computer programs [Bers, 2010], and through the process of programming can explore and comprehend a wide range of "powerful ideas" [Papert, 1987] that extend from STEM to CT [Benitti, 2012]. The programmer has to think mainly about the goal of the robot and how the robot will interact with the environment. However, there is another important aspect that should also be taken into consideration, and this is if and how the user will physically interact with the robot. Putting forth the notion of child-robot interaction, we are moving away from the conventional and well-established robotics curriculum, where students ought to program an autonomous robotic agent, to programming activities promoting a close interplay between children and robots. Overall, the curriculum will target secondary education students. Nevertheless, with some small modifications, it could be also applied in the future in lower educational levels, such as primary education.

The curriculum will be divided into three individual but complementary sessions. In Table 1 we present what kind of applications students will be asked to develop and the concepts that will be

[1] https://en.wikipedia.org/wiki/Capture_the_flag

[2] https://www.robotvirtualworlds.com/

Table 1: Overview of the activities and the concepts that will be explored in each session of the Curriculum

Session	Activity Title	Student should . . .	Concepts Explored
1	Teleoperation	design human-robot interfaces to play the 2vs2 CTF game. Humans controlling the robots (first-person projection) with joysticks, computer vision technology, or mobile technology devices to achieve the collective goal.	game design, programming, human-robot interfaces, kinematics
2	AI	integrate AI into the robots to play the 2vs2 CTF game. Robots are operating autonomously, while collaborating with team members, to achieve the collective goal.	game design, programming, visual perception, tactile sensing, synchronous motion, Math and Trigonometric functions, Math to calculate motion pathways, logic, and problem-solving.
3	Teleoperation with AI partner	design human-robot interfaces and integrate AI into the robots, to play the 2vs2 CTF game. Each team consists of one robot controlled by a human and another collaborative robot (cobot) operating autonomously. Humans and robots collaborate to achieve the collective goal.	game design, collaborative robotics, programming, human-robot interfaces, visual perception, tactile sensing, speech recognition, synchronous motion, Math and Trigonometric functions, Math to calculate motion pathways, logic, and problem-solving

explored during each session. We aim to investigate various learning aspects of the interrelationship between the robot, the user, and the environment. In the first session, we intend to address the physical interaction aspect between the student and the robot, as participants will design and develop human-robot interfaces. They will control the robots through teleoperation using their bodies as input for the interaction. In the second session, we will apply a typical educational robotics activity, as participants will program the robots to operate autonomously in the environment. Finally, in the third session, we propose an intervention with an embodied learning perspective that blends the traditional autonomous robotic movement with student enactment.

2.3 Gameplay

Students and their robotic co-players will be split into two different teams to play the 2vs2 CTF game in various ways. An example scenario of the game is illustrated in Figure 1. A local participant has gained access, wirelessly, to a robotic agent with his mobile phone and collaborates with another robotic agent that operates autonomously (green team). The opposing red team is made up of two robotic agents that are controlled by two participants connected remotely through the internet. Each team will have a base where the flag will be allocated inside the arena. The goal of the game will be to capture the enemy's flag, using the robotic agents, and bring it to the base as many times as the game organizer decides [Hauge et al., 2017]. Additionally, the robotic agents will have to protect their flag.

The multiplayer element can lead to a greater connection, cooperation, presence, and positive mood among the players than playing with a computer [Vella et al., 2017]. Multiplayer games take advantage of competitive, cooperative, or collaborative gameplay mechanics, following different advantages and limitations [Zagal et al., 2006]. Although competition is a common element of video games, providing players with the task to overcome a series of automated obstacles or even other players, most games take advantage of a combination of collaboration and competition. Therefore, the multiplayer element could be an important aspect of designing a serious game with robotic agents.

Additionally, the practice of using CTF gamified activities and competitions is particularly successful in introducing cybersecurity to college and high school students [Ford et al., 2017, Li and Kulkarni, 2016]. Competitive context-aware activities, such as CTF, have been previously considered for teaching STEM concepts as part of gamified learning paths [Hauge et al., 2017]. The CTF approach has been also applied to teach robotics during a four-week summer short course where students programmed GPS-guided autonomous robots to compete in a CTF activity [Danowitz et al., 2017]. Gamified educational activities while interacting with teleoperated robots can be used not only to foster children's perspective-taking ability but also to allow them to explore STEM concepts such as arithmetic [Yadollahi et al., 2020]. It seems that game-based activities, with an embodied learning perspective, might be an innovative way to engage both boys and girls in robotics. Still, longitudinal research and evaluation are necessary to determine whether the proposed approach can maximize the learning potential for both boys and girls.

2.4 Materials

We are inspired by the mars rover exploration missions so the educational robots for supporting the curriculum will be similar to those used in the Mars rover expedition. Both Lego Mindstorms and Arduino open-source robotic toolkits can be assembled in a way to provide a mars rover-like robot. A mars rover-like robot has certain capabilities that allow it to operate dynamically in complex environments, and this is the main reason for its selection. Additionally, by using a mars rover-like robot, participants will be able to connect the science content explored in the curriculum with real-world applications. [3]

We intend to employ a blocks-based visual programming environment, such as Blockly[4], as the development platform. Blocks-based

[3]Clipart: https://thenounproject.com/
[4]https://developers.google.com/blockly

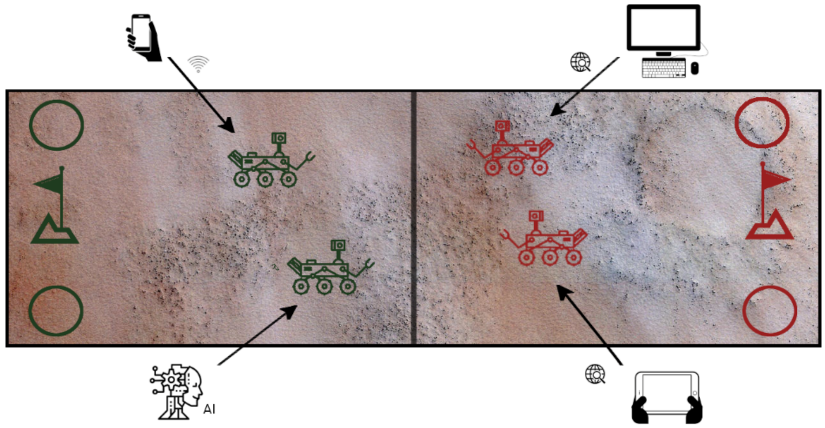

Figure 1: Block diagram showing an overview of the open space's design and the diverse styles for controlling the robotic agents locally and from a distance.

visual programming languages are based on the idea of snapping blocks together, which is inspired by Legos, and offer a low floor, high ceiling, and wide walls learning environment [Resnick et al., 2009]. Students are not permitted to make syntactic errors, as the shape of the command blocks determines the ways that blocks can fit together while the drag-and-drop system refuses connections that do not make sense. Thus, they can entirely concentrate on the semantic of the code rather than on the syntactic.

2.5 Measuring Instruments and Data Analysis

For assessing the learning impact of the curriculum we will collect and analyze both qualitative and quantitative data. We are primarily interested in assessing the development of CT skills during the curriculum and, secondarily, the impact of the curriculum on the comprehension of abstract STEM concepts. We intend to apply Brennan and Resnick's [Brennan and Resnick, 2012] framework for assessing the development of CT. Brennan and Resnick [Brennan and Resnick, 2012] proposed three CT dimensions: computational concepts, practices, and perspectives. Computational concepts refer to the fundamental elements that are commonly present in many programming environments such as sequences, loops, parallelism, events, conditionals, operators, and data. Computational practices are activities that may occur during the process of construction, such as experimenting and iterating, testing and debugging, reusing and remixing, and abstracting and modularizing. On the other hand, computational perspectives capture young learners' shifting viewpoints about themselves (expressing), their relations with others (connecting), and the world (questioning), as they engage in CT activities.

By analyzing students' projects in each session of the robotics curriculum, we can focus our assessment on the first dimension in Brennan and Resnick's CT framework: computational concepts. The projects will be graded based on a rubric similar to the one proposed by Werner et al. [Werner et al., 2020] used for grading student-made computer game projects. By recording and analyzing students' on-screen activity as they develop their applications we can gain an overview of their computational practices, which constitute the second dimension in Brennan and Resnick's CT framework. Finally, with the use of interviews and questionnaires, we aim to capture the shift in participants' computational perspectives.

3 DESIGN IMPLICATIONS AND FUTURE WORK

In this paper, we present the initial design of an open space that will allow children to gain access, locally and remotely, and program robotic agents to play the traditional CTF game in a physical stadium arena. Through this space, we intend to teach robotics, while programming human-robot interfaces, within a game-based CSCL environment. The actual implementation of the open space hasn't yet started, however, the expected outcomes of the educational use of the proposed platform will address several scientific and practical issues within the field of computing education. In terms of scientific contributions, it can lead to insight and new knowledge in various academic areas, such as child-robot interaction, embodied learning, educational robotics, and learning with serious games. Specifically, within the domain of educational robotics, the proposed robotics curriculum has some strong implications for how robotics can be taught in workshops, competitions, and especially in classrooms. In this way, the established curriculum of programming an autonomous robot might be complemented with user interactions, as well as with hybrid modes that reflect the variety of human-robot interactions in research and practice [Beer et al., 2014]. Additionally, the implementation of a serious multiplayer competitive game with robots, such as the CTF, could further enhance the learning process, as this synergy would combine the benefits of educational robotics and those of serious games. As for the practical benefits, the proposed platform can offer students open access to computationally enhanced educational manipulatives, locally and from a distance. In this way, we can distribute the pedagogical content outside the formal educational settings, creating an open space for experimentation and learning, and therefore making robotics more approachable.

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