Expanding the Curricular Space with Educational Robotics: A Creative Course on Road Safety

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Abstract. While initiatives worldwide continue to place pressure on schools to improve STEM education, the already overcrowded curriculum often leaves little space for the integration of new courses or topics. Numerous benefits are reported in the literature about the use of educational robotics; yet, their integration in school contexts requires time that cannot be taken from other important courses. In the end, most educational robotics activities are done outside the curriculum such as in after-school programs and summer camps. The major contribution of this work is the presentation of a case of creative and non-intrusive integration of educational robotics to support the current school curricula. We present an example of expanding the curricular space, by integrating educational robotics in an existing course unit. In the absence of formal educational robotics curriculum and courses, the study presents an exemplar case of educational robotics integration in a creative and non-intrusive way. The lesson design and implementation are presented; the creative infusion can be realized and holds benefits for the students. Through educational robotics, students can practice new skills such as problem solving and teamwork, while they gain knowledge in the specific domain of the course unit.

Keywords: Educational robotics · Technology integration · K-12
Expanding the curricular space · Bee-Bot

1 Introduction

In the recent years, there has been an increased interest in the educational use of robotics with numerous attempts to integrate the technology from kindergarten to university level worldwide [1]. Within a (social) constructivism spirit, the use of educational technology aims to enable students to engage in problem-solving, collaborative learning and creative thinking; educational robotics is considered one such technology, whether it is used to teach specific content in a domain such as engineering or is designed to work as a construction and programming tool for promoting problem solving and computational thinking [2]. Today, educational robotics is seen as an innovative, progressive and versatile educational tool for teaching and learning, that is also fascinating for students of all ages [3]. Several authors have reported learning gains as a result of student engagement with various robotics projects, including the development of problem solving, creativity and collaboration skills [1].

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Overall, educational robotics has emerged as a unique educational tool that can provide hands-on activities in an attractive learning environment, boosting students' interest and curiosity [4, 5]. Yet, despite the great interest developed around this topic, formal educational robotics curricula and courses are currently lacking in K-12 schools around the world. Simply, the overcrowded K-12 curriculum leaves little time for dedicated courses or units. Therefore, most educational robotics activities are done outside the curriculum such as in after-school programs and summer camps [6]. The present study aims to investigate how educational robotics can be integrated in existing school subjects, in a creative and non-intrusive way, therefore expanding the curricular space (i.e., learning about robotics and computational thinking while learning language). That is, the authors sought to present a case of technology integration which expands the curricular space in that it allows students to practice skills such problem solving and teamwork while they work on a subject of the school curriculum. The overarching research question of the study was:

RQ: How educational robotics may be realized as means for expanding the curricular space via their creative integration in current school subjects?

2 Background Work

Literature reveals that educational robotics is a growing sector with the potential to significantly affect the nature of science and technology education (i.e., STEM education), from kindergarten to tertiary education [1, 7]. There are a number of reports resulting from various educational robotics programs about educational robotics improving the performance of students in mathematics, physics and engineering [1]. Moreover, researchers [8] have found that students who attended robotics courses developed powerful logic and critical thinking skills, oral presentation and teamwork skills. When dealing with robotics, students are stimulated to identify the problem, to analyze and explore possible solutions to achieve the objective, and to check their solution with the appropriate control procedures e.g., evaluating the solution in terms of functionality [6]. In general, the role of educational robotics should be considered broadly, as a tool that can support the development of a variety of skills, including cognitive skills, personal development, and collaboration skills. Researchers have argued that educational robotics offer special educational advantages, because the technology is interdisciplinary in nature and includes a synthesis of many technical issues, including algebra and trigonometry, design and innovation, electronics and programming, the forces and the laws of motion, as well as other materials and hands-on processes [9]. It is for this reason – the interdisciplinary nature of the technology – that the present investigation considers ways to integrate robotics in the existing school curricula, as opposed to suggesting dedicated educational robotics courses and curricula.

Research on educational robotics is typical seen through the lens of constructionism [10]. Constructionism argues that learning occurs when the student creates a physical structure that reflects the experience of solving problems, relying on incentive received from the construction of the object itself [10]. Generally speaking learning that is driven by problems (problem based learning) allows the learner to build his/her own knowledge. In this spirit, educational robots are essentially a constructionist tool, with which students interact and utilize their knowledge and experience to solve real problems by developing and testing their solutions [11, 12]. A typical lesson plan in educational robotics includes an initial introduction to programming the robot, followed by student practice on applying their knowledge to make the robot work [13].

One of the main weaknesses in the area of educational robotics is the absence of clearly defined curricula, educative material for teachers and learners, as well as a repository of available kits and their capabilities [2]. What's more, educational robotics is most often seen as an extra-curricular activity and as part of informal education. Efforts should be made to design educative material for educational robotics linked to existing school curricula and taking advantage of the capabilities of available (and affordable) educational robotics kits. With no doubt, teacher professional development on the integration of educational robotics is imperative; teachers need to see educational robotics as a teaching tool to enhance the learning process, complement the learning experience, and provide incentives for students, while the role of the teacher remains of great importance in supporting and scaffolding the learning experience [13].

Overall, while initiatives worldwide continue to place pressure on schools to improve STEM education, the already overcrowded curriculum leaves little space for the integration of new courses or topics [14], such as that of educational robotics. The present study aimed to investigate how educational robotics can be integrated in existing school subjects, in a creative and non-intrusive way, therefore expanding the curricular space. Similar initiatives have been previously considered by others. Although not in the area of educational robotics, the GlobalEd 2 project also builds on the idea of expanding the curricular space; it builds upon the interdisciplinary nature of the social studies course in the schools of USA and integrates technology (i.e., a simulation web-based environment) aimed at increasing the instructional time devoted to science and persuasive writing [14]. On the other hand, from an interest and gender differences point of view, researchers [15] have suggested that educational robotics should be integrated into the curriculum of subject areas such as art, music and literature, to meet the interests of a diverse population of students. The authors' [15] argument was based on the premise that meeting students' personal interests allows them to persist more when they encounter problems and to continue to expand their exploration to new directions. For example, in one of their studies, the topic was the park; students had to remember their experiences at a park (e.g. seeing a dog chasing a cat) and they had to use educational robots to represent their experience. By incorporating the history narrative (storytelling) in the robotics activity, the students improved their reading and writing skills [15].

3 Method

This work aimed to present a case of creative and non-intrusive integration of educational robotics in the overcrowded school curricula. Student questionnaires were administered to understand the experience from the students' point of view, whilst teacher interviews were conducted to understand the experience from the teachers' perspective, strengthening the evidence and enhancing the validity of the findings.

3.1 Participants

Participants were 43 students and 3 educators, coming from one private and two public schools in Northeastern Europe. Specifically 10 second-graders (3 girls and 7 boys) with their (female) teacher came from a private school, and 33 second-graders (15 girls and 18 boys) and their two teachers (females) came from two classes in a public school. None of the participants (teachers and students) had previous experiences with educational robotics.

3.2 Procedures

Teaching "road safety" is part of the country's teaching requirements, found as a unit in the subject of "general citizenship and wellbeing". In this study, "road safety" was addressed (and is typically addressed) during the first two weeks of October, both in the public and private schools.

We used Bee-Bots, a commercial programmable floor robot kit. Based on BeeBot.us, the robot's friendly layout appeals to children and can be a starting point for teaching control, directional language and programming to young children.

There was a preparation phase, during which the researchers and teacher of the private school worked closely together to co-design lesson plans to integrate Bee-Bot in the "road safety" unit. Several lesson plans were designed using freely available Bee-Bot mats and other images (e.g., policeman, stop-sign, pedestrian cross) located online such as at http://www.twinkl.co.uk/, printed in A4, plasticized, and assembled on the classroom floor for group activities (i.e., one mat for each group).

The first lesson used a testing mat (see Fig. 1) and aimed to familiarize students with Bee-Bot by practicing with the following: Bee-Bot tabs, directional commands, termination; decoding tabs to understand the resulting movement and verifying the answer. This lesson was completed as a class-wide experience in front on a single mat and using one Bee-Bot.

Fig. 1. First lesson with Bee-Bot and testing mat.

Following the first lesson, all Bee-Bot activities focused on “road safety”. Students worked in groups of 3–5 students, in front of a mat. Typically, the teacher together with the students formulated a problem scenario e.g., Bee-Bot needs to reach a hotel, following policeman commands such as stop signs placed in various places. Setting the starting point and ending point, including direction of the Bee-Bot on the mat, was part of the problem definition. Figure 2 illustrates the typical structure of a lesson plan. Lesson plans became progressively more difficult (i) in terms of problem solving e.g., Bee-Bot had to follow a more complicated path in reaching the ending point via obstacles and only a single trial was allowed for the team, and (ii) in terms of knowledge about “road safety” i.e., Bee-Bot had to understand commands by the policeman such as a stop sign or diversion and had to consider pedestrian crosses. Figure 3 presents some episodes from the school implementation. In sum, the curricular space was expanded in that the lessons targeted problem solving (e.g., computational thinking) and teamwork skills together with knowledge about “road safety”.

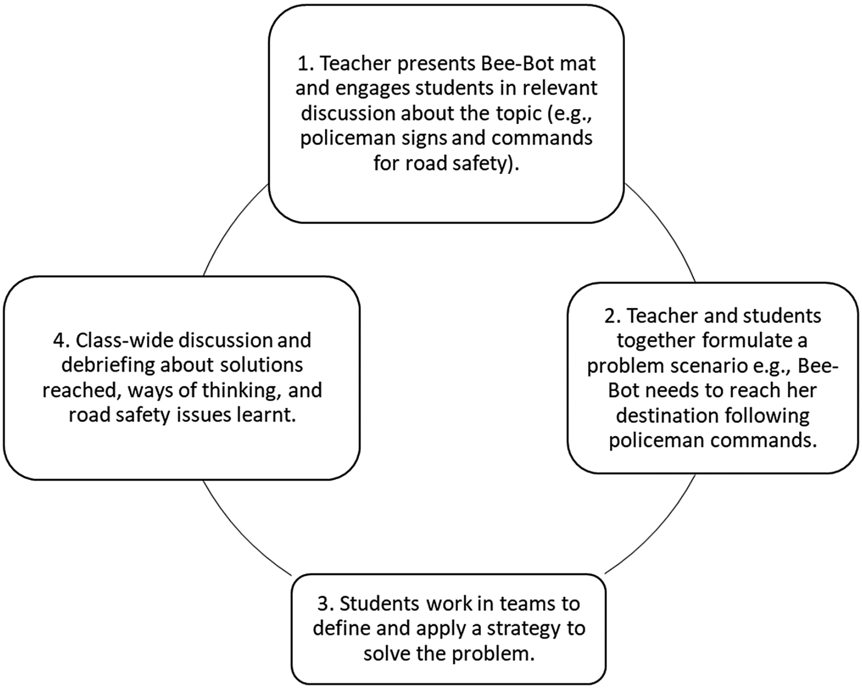

Fig. 2. Typical structure of a lesson plan.

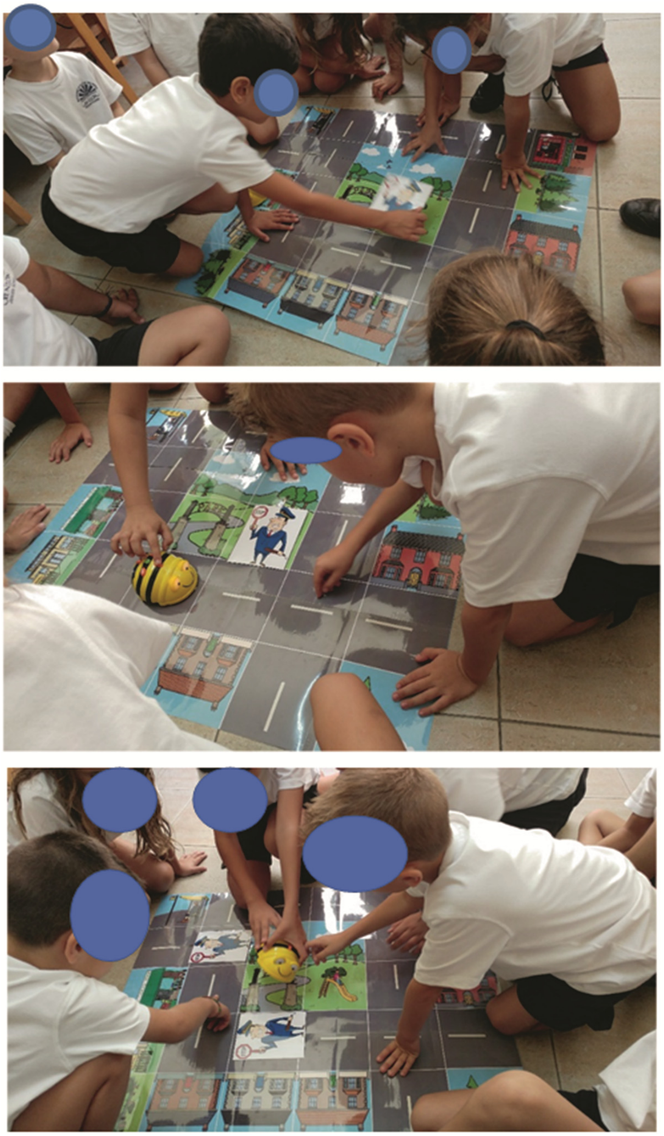

Fig. 3. Lesson plan implementation with 2nd graders

3.3 Data Collection

For the duration of two weeks in October 2016, the researchers observed 10–11 teaching sessions (45 min each session) implementing the series of lesson plans in each participating school. All participants signed informed consents and were aware of the roles of the researcher-observers in the field. At the end of all lessons, a 30-min semi-structured interview was conducted with each of the participating teachers with the double scope of understanding: (i) how the experience was good (or not), and (ii) what can we learn about the integration of educational robots in existing school topics and curriculum. Moreover, at the end of the experience, the participating students (N = 43) completed a 7-item attitudinal questionnaire regarding their overall experience (see Fig. 4).

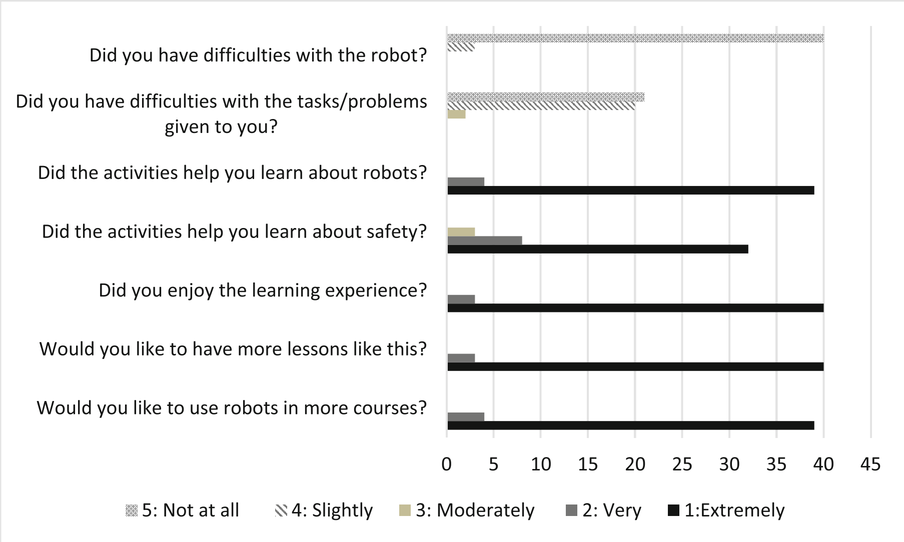

Fig. 4. Students' perceived experiences (N = 43)

4 Analysis and Results

All students (N = 43) completed the questionnaire supporting our understanding of the experience from the students' point of view. The teachers' perspective (via interview data) was analyzed thematically to extend our understanding of the experience.

4.1 Students' Perceived Experiences

All students (N = 43) completed the questionnaire. Results demonstrated that the integration of educational robotics in the existing curriculum was fully endorsed by the participants. As illustrated in Fig. 4, all students thought that the lessons were enjoyable whilst they allowed learning about robots as well as "road safety".

4.2 Teachers' Perceptions

Teachers' semi-structured interview data were transcribed and analyzed. A thematic analysis was conducted by two researchers, working closely together to identify core consistencies and meanings (themes) in the pool of qualitative data (Patton, 2014). In general, no variations were noted in the three teachers' perceived experiences across public (2 classrooms) and private schools. We report on these themes next, organized within the double scope of the interview.

How was the experience good or not?
All three teachers fully endorsed the integration of Bee-Bots in the school lesson on "road safety" as well as the overall idea of using educational robots to expand the curricular space to address skills (e.g., problem solving) beyond knowledge on the matter. The teachers deemed this approach of technology integration as *non-intrusive with valuable learning benefits* (theme 1). As one of the teachers argued:

> "The students were not destructed by the playfulness of the Bee-Bot, but rather they exhibited learning gains from this experience as they discussed about "road safety", namely stop signs and pedestrian crosses, problem-solved with their Bee-Bot, evaluated and improved their solutions, and explained their thinking to others during our class-wide discussions."

Moreover, the teachers endorsed the *emerging gameful character* (theme 2) of the overall experience, which was considered valuable for collaborative learning and teamwork. As the teachers explained, students, within their team, engaged in collaborative learning and problem-solving targeting a common goal; collaboration was better and better as lessons progressed. Between teams, competition dynamics emerged naturally and were enriched by the teacher's praise and rewards for good problem-solving and collaboration. The gamefulness of the activity was further promoted by social rewards or peer pressure by teammates of the owned group or the competing group. The benefits of gameful learning have already been discussed in [16], consistent with the teachers' perspectives in the present study.

Furthermore, the learning experience was perceived as *engaging and embodied* (theme 3). Students were present, mentally and physically and while planning their strategy, they often used their bodies to support their thinking. For example, students stood up and performed the steps and turns on the mat, before enabling the Bee-Bot (especially when only one trial was allowed), or after they realized an unexpected outcome (i.e., to help decoding the error). In the teacher's own words:

> "The activity engaged their bodies and minds and motivated participation even from the quietest students. They often stood up and 'tested" the steps using their bodies to support their thinking […] They enthusiastically planed their Bee-Bot path solution which involved domain knowledge, for example, Bee-Bot as vehicle stops at stop signs, and they had a lot of fun seeing the result of their planning. And if the solution was not correct, they decoded their solution to understand what went wrong, which helped them practice their problem-solving skills."

What can we learn about the integration of educational robots in existing school topics and curriculum?

Not surprisingly, the teachers explained that *careful planning and access to resources* (theme 4), such as lesson plans and mats for the robot, are needed for successful integration of education robots. As they noted, understanding the functionality of the technology is imperative, but a good knowledge of the daily curriculum and school topics is also required, before the educator can think of effective learning activities around educational robotics. That is, the curriculum goals need to be fully addressed, whilst additional opportunities for learning are mediated by educational robotics, such as the development of problem solving and computational thinking skills.

According to the teachers, this planning might take quite longer than typical lesson preparation and might not be something a novice teacher would undertake unless s/he has support and access to relevant, open educational resources. In the teacher's own words:

> "You need to make sure the objectives of the curriculum are met and that the robotic activities will not drift attention away from these objectives, but rather, will add to it, by enabling additional types of skills such problem solving. This planning is not easy to do before you are well familiar with the daily curriculum and school topics and you also understand the technology [….]. Open educational resources can help a lot; for example, although I can now think of amazing lessons plans for the upcoming units, I don't have the skills to design the Bee-Bot mats."

Nevertheless, given good preparation took place in this study, all teachers agreed that that series of lessons were successful in meeting the curriculum goals on "road safety" as well as expanding students' opportunities to engage in problem solving and teamwork. Moreover, they stated how, upon this experience, they could already think of numerous lessons for expanding the math and language curricula using Bee-Bot, such as for example, using a mat with shapes, numbers, and symbols for addition, subtraction, multiplication, and division in math.

In terms of implementation, after the first lesson, no guidance was needed in using the robot. Teamwork was a challenge only in the first couple of lessons during which, students exhibited lack of cooperation (e.g., all wanted to handle the Bee-Bot). Perhaps this was due to the enthusiasm caused by the novelty of the task; *teamwork and collaboration around the robot got better as the lessons progressed* (theme 5) and as students realized that group work had value into getting the task completed successfully. Students leant to divide responsibilities within the group using a rotation pattern; this practice was realised in all three classes, after the first couple of lessons, and it mostly the students' owned initiative (e.g., deciding and assigning roles), as initial evidence of teamwork skills being developed. All three educators agreed that small groups (3–5 students) worked well, which is consistent with previous practice and findings in educational robotics [3].

5 Discussion and Conclusions

While initiatives worldwide continue to place pressure on schools to improve STEM education, the already overcrowded curriculum often leaves little space for the integration of new courses or topics. Numerous benefits are reported in the literature about the use of educational robotics; yet, their integration in school contexts requires time that cannot be taken from other important courses. In the end, most educational robotics activities are done outside the curriculum such as in after-school programs and summer camps [6]. Yet, the increasing availability of educational robotics kits and the growing interest in their use by researchers and practitioners, presents an opportunity to examine issues of technology integration in creative and non-intrusive ways. The present study aimed to investigate how educational robotics can be integrated in an existing school subject, expanding the curricular space by allowing the development of robotics, problem solving and teamwork skills together with domain knowledge.

Findings from this study support the researchers' standpoint about the value of using educational robotics to expand the curricular space. The study presents evidence that this approach is non-intrusive, but rather engaging [8], embodied [12], and gameful [16] with valuable learning benefits around problem solving and teamwork. Although, the infusion of educational robotics requires some extra preparation on behalf of the teacher, the benefits seem to be rewarding. With careful design, a cognitive bridge is created between curriculum objectives and the educational robotics experiences, encouraging students to acquire content knowledge in addition to other types of skills [6]. These findings, although preliminary, are strengthened in terms of consistency across data sources (i.e., student questionnaires and teacher interviews) and school settings (i.e., implementation in one private and one public school with three educators involved).

Overall, the study demonstrated a case of creative and non-intrusive infusion of educational robotics in the existing curricula, in the absence of time for dedicated educational robotics courses. The approach was deemed appropriate and beneficial for students, showcasing educational robotics as means for expanding the curricular space to allow for the development of robotics, problem solving (e.g., computational thinking) and teamwork skills together with domain knowledge. We understand that our data are preliminary and rely on self-reported measures and observations; yet, a major contribution of this work is the realization of a method toward creative and non-intrusive integration of educational robotics in the overcrowded school curricula. Future work should aim to objectively document student learning gains in an expanded curricular space using educational robotics. Future work should also aim to create open educational resources relevant to this idea via the infusion of educational robotics in existing school curricula and topics. Furthermore, while enabling teachers to develop and teach educational robotics as a core curriculum course might be an important goal [17], we would further argue that teacher professional development should present successful examples and provide inspiration for the creative integration of educational robotics in the existing school curricula. We hope that the encouraging findings of this work will motivate further research and practice in this area.

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