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Educational Robotics along with Arts join forces to cultivate Computational Thinking

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Abstract

The COVID-19 pandemic opened up opportunities for a digital transformation in Educational Robotics (ER) towards applying innovative approaches including the use of simulators. The Erasmus+ "FERTILE" project, a partnership of five European universities, further addresses the potential of ER and Arts joining forces towards cultivating Computational Thinking (CT). Following a Design-Based Research (DBR) approach, we initiated our efforts by investigating educators' experiences and views on their challenges and the support they need to evolve their practices towards an interdisciplinary approach combining Robotics and Arts in a blended learning context. This paper presents the study conducted to gather insights from various European educators across different educational levels. The findings about educators' design ideas for interdisciplinary activities included several art forms and methods for interweaving Robotics with Arts. The main challenges reported were (i) interdisciplinary collaboration, (ii) curriculum lacking an interdisciplinary approach, and (iii) designing learning experiences. Notably, educators' current practices of cultivating their students' CT skills involved an underlying inexperience in conceptualising CT and approaching it merely as problem-solving. Lastly, the support the educators required around (i) educational context, (ii) learning content, and (iii) design issues; highlighted the need for a robust design methodology, a community platform and effective training.

Keywords: educational robotics, arts, computational thinking, blended learning, robotic simulators, interdisciplinarity

Introduction

Studies investigating the impact of Educational Robotics (ER) on academic and social skills provide evidence for its effectiveness in developing digital skills, Computational Thinking (CT), as well as for general benefits positively affecting students' personal development (Angeli & Giannakos, 2020). ER increasingly appears in formal and informal educational settings for students of all ages, as robotics kits and visual programming environments are considered the most appropriate tools to teach, learn and assess CT (Bocconi et al., 2022).

The COVID-19 pandemic has abruptly discontinued ER implementation at all educational levels, from elementary to vocational education and universities. Students lost access to the classroom and school laboratories, limiting them to using tools they had at home (Alves Gomes et al., 2020). To this end, teaching practices went beyond educators presenting ER while students were passive viewers, including simulators. Unlike physical educational robots, which are not always easy to transport, simulators consist entirely of software, thus allowing students to engage with robotics at any place and time as long as they have a computer or tablet (Tselegkaridis & Sapounidis, 2021).

We argue that the aftermath of the pandemic opened up opportunities for a digital transformation in ER towards applying innovative approaches, including simulators in a blended learning context. Aiming to contribute to this area, in the context of the Erasmus+ "FERTILE" project (https://fertile-project.eu), we further address the potential of ER and Arts joining forces towards cultivating CT skills. To this end, we go beyond the traditional approach of ICT educators using Arts as a stimulus for developing robotics constructions that either draw designs (e.g. Souliotou, 2019) or produce sounds/music (e.g. Baek & Taylor, 2020). We focus on CT as fundamental for everyday problem solving, influencing nearly all disciplines, and use it as a boundary object (Caccamo et al., 2023) to support communication between the disciplines of Informatics/ICT and Arts. In such a context, the "FERTILE" project's objective of empowering educators to design and implement impactful learning experiences collaboratively remains a major challenge that has not been studied yet.

Although the projects' background is multidimensional in the areas of ER, Arts, CT and their interconnections, this paper focuses on asserting CT within the state-of-the-art European educational transformation. Therefore, in what follows, we explore an indicative sample of how CT is integrated into curriculums by presenting our research findings on the countries participating in the FERTILE project: the Czech Republic, Greece, Slovakia, and Spain. Then, we present a study conducted in the initial cycle of the Design-Based Research (DBR) approach (Amiel & Reeves, 2008) that project partners adopted to develop the "FERTILE" design methodology. This methodology aims to support educators towards interdisciplinary practices combining Robotics and Arts in a blended learning mode to cultivate their students' CT skills. Considering educators' views as a fundamental issue contributing to the effective transformation of educational practice, this study gathered insights from various educators across different educational levels. The aim was to explore educators' experiences and views on their challenges and the support they need to evolve their practices. The paper concludes with a critical overview of the findings and how they will drive the projects' deliverables development, including a community platform enabling teachers to co-design and adequate training in the "FERTILE" design methodology.

CT in the 4 European countries' curriculum

Computational Thinking has been recognised as a 21st-century literacy (Mohaghegh & Mccauley, 2016). A main challenge reported is finding appropriate *pathways to cultivate CT throughout compulsory education* (Bocconi et al., 2016). From the teachers' perspective, several questions are raised mainly *whether teachers have computational thinking pedagogical capabilities as well as the critical professional development and training areas for teachers* (Bower et al., 2017). Given the variation in definitions and the different CT skills found in the literature, teachers' difficulty in applying and conceptualising CT is not particularly surprising (Fessakis & Prantsoudi, 2019).

The integration of CT in school curricula varies from country to country (Bocconi et al., 2016). In some cases, it is integrated across subject areas, while in others, it is part of a separate computing subject. In addition, these two approaches are often combined. There is a profound relationship between CT and disciplines such as Informatics, Mathematics, and Science due to common approaches such as problem-solving, modelling, and data analysis and interpretation (Shute et al., 2017). On the other hand, it seems more difficult to connect CT with Arts, although proposals on cultivating CT through Arts have recently appeared (De

Paola et al., 2018). As a result, several examples emerge in the literature about cultivating CT through editing or dramatising literature (Bravo et al., 2021), analysing diverse artistic movements (Souliotou, 2019), and composing music (Greher & Heines, 2014; Chong, 2019). In this line, we exploit CT as a boundary object between the subjects of Informatics (through ER) and Arts.

However, effective integration of an innovative interdisciplinary approach to cultivating CT in educational practice, requires alignment with the official curriculum of the respective countries and regions. Lately, CT has been integrated into several European countries' official curricula, mainly related to Informatics (or Computer Science) subjects. Below, we provide a brief overview of the integration of CT in formal education (focusing on Informatics and Arts subjects) of the countries participating in the "FERTILE" project: the Czech Republic, Greece, Slovakia, and Spain.

In the **Czech Republic**, a new national curriculum for primary and lower secondary education will be effective starting in the school year 2023-2024. A significant change was replacing ICT with "Computer Science" while including new content and objectives focusing more on CT, including four main topics: digital technologies, information systems, data, information and models, algorithmisation and programming (Ministry of Education, Youth and Sports, 2021). The "Arts and Culture" (music education and art education) subject contains no activities or objectives related to CT.

In **Greece**, the new ICT curriculum (Institute of Educational Policy, 2022) sets CT as a primary and secondary education objective, replacing the earlier "algorithmic thinking" objective. It is mapped to various curricular units, and its value is emphasised as a problem-solving competence related to computer programming and as a conceptual framework for promoting interdisciplinarity in education. At the same time, the Greek Arts curriculum (arts & crafts, music, drama) does not include any CT objective. Still, some modules relate to authentic problem-solving, connecting arts to other disciplines, and exploratory learning.

In **Slovakia**, curriculum reform is currently ongoing. The current National Curriculum for primary and secondary education includes the subject of Informatics from the third year of primary school onwards (National Institute for Education, 2023). Informatics at high school still follows the 2015 National Curriculum. Besides developing IT literacy, Informatics' main objective at all educational levels is CT cultivation through problem-solving, algorithmic tasks, creating programs, working with different data and data structures, and recognising a solution's correctness and a problem's solvability. Regarding Art subjects (music, fine arts), in addition to their primary objectives, cultivating students' CT-related skills has been set, such as understanding a particular artwork's structure, evaluating artefacts in terms of their function in human life, working creatively on a given problem, adopting an appropriate strategy, analysing, and forming a solution.

In **Spain**, the curriculum is also under reform following directions from the Computer Science Society and the Council of Deans of Schools of Informatics (Velázquez-Iturbide, 2018). They recommended establishing a new course on Informatics, which should include areas such as programming, computers and operating systems, networks, data, digital content and security. In 2020, the Organic Law in E-education spotlighted CT, emphasising learning programming and developing CT starting in childhood education. Art is a specific subject that depends on the regulations established by each educational institution. Although it has no objectives set for CT, some units may relate to CT skills.

In line with the European transformation towards curriculums that include CT within the objectives of computer science-related subjects, the "FERTILE" project caters to the state-of-the-art European educational transformation by cultivating students' CT skills and the

European priority of digital transformation by exploring ways to cultivate CT in a blended learning context. Although national curriculums do not officially include CT objectives in their Arts-related subjects, we identified some CT-related skills that indicate the Arts' potential to cultivate CT. Thus, the "FERTILE" project's exploration of Robotics and Arts interdisciplinarity targets to provide evidence towards such a viewpoint.

Methods

The study described in this paper initiated the FERTILE project's exploration of educators' profiles aiming to gather insights from various educators across different educational levels. Initially, we followed a quantitative research design, distributing an online questionnaire to educational communities of Informatics/ICT and Arts educators to collect their experience on ER, Arts, CT and their interconnections. We analysed 134 responses focusing on teaching experience i) with ER or ER simulators and ii) designing and applying interdisciplinary activities with Robotics and Arts. Subsequently, opting for a purposive sample of educators having such an experience, we selected 61 educators: 17 Greek (GR), 16 Slovak (SK), 15 Czech (CZ), and 13 Spanish (SP). Table 1 summarises their demographic characteristics.

Table 1. The participants' demographic characteristics (n=61)

Characteristic	Characteristic	GR	SK	CZ	SP
Sex	Male	5 (41%)	6 (37%)	3 (20%)	6 (46%)
	Female	12 (59%)	10 (63%)	12 (80%)	7 (54%)
Educational Level	Primary	8 (47%)	5 (31%)	7 (47%)	4 (31%)
	Secondary	7 (41%)	7 (44%)	4 (27%)	7 (54%)
	Higher	2 (12%)	4 (25%)	4 (26%)	2 (15%)
Discipline	ICT	14 (82%)	15 (94%)	13 (87%)	11 (75%)
	Arts	3 (18%)	1 (6%)	2 (13%)	2 (15%)
Teaching Experience	Novice	15 (88%)	11 (69%)	5 (33%)	4 (31%)
	Expert (>13years)	2 (12%)	5 (31%)	10 (77%)	9 (69%)

Afterwards, using this sample, we followed a qualitative research design, conducting focus groups and interviews to address the following research questions:
Research Question 1 (RQ1): *What design ideas do educators have, and what challenges do they face while developing ER and Art interdisciplinary activities?*
Research Question 2 (RQ2): *How do educators design ER activities to cultivate their students' CT, what challenges do they face, and what support do they require?*

Data Analysis and Results

Applying an inductive coding process, each partner analysed its qualitative data. After several analysis iterations, we concluded with a common coding scheme to ensure consistency. Then, we computed the frequencies per country and the average frequency to enable consideration within the respective national contexts and European tendencies. Due to space limitations, this paper presents the top three results reported.

RQ1: What design ideas do educators have, and what challenges do they face while developing ER and Art interdisciplinary activities?

Regarding the participants' design ideas, the typical art forms considered for interdisciplinary activities involved:

- Arts and crafts (GR:64%, SK:43%, CZ:47%, SP:35%, Average:47%)
- Performing arts (music, dance and theatre) (GR:20%, SK:57%, CZ:27%, SP:50%, Average:38%)
- Literature (GR:16%, SK:0%, CZ:7%, SP:15%, Average: 10%)

The most frequently reported design ideas were:

- Program robots to perform Art (GR:28%, SK:7%, CZ:27%, SP:35%, Average:24%) for activities involving programming robots to perform Art. For instance, robots may be the characters in a play; they may play music or dance on specific steps.
- Create artful robots to perform Art (GR:12%, SK:7%, CZ:20%, SP:25%, Average:16%) for activities involving constructing robots with artistic materials, such as painting or dressing them in costumes designed by the students.
- Program robots to create Art (GR:16%, SK:13%, CZ:20%, SP:0%, Average:12%) for activities involving programming robots to create an artefact/piece of Art, e.g. robots using a pencil or a marker or pouring paint to draw on paper/surface.

Regarding the challenges that participants faced, the following categories were specifically related to interdisciplinarity:

- Achieving interdisciplinary collaboration (GR:22%, SK:27%, CZ:8%, SP:29%, Average:22%) in terms of (i) not sharing common working hours with their peers, (ii) different mindsets toward collaboration, and (iii) focusing on robotic competitions.
- Following curriculums lacking an interdisciplinary approach (GR:4%, SK:8%, CZ:0%, SP:0%, Average:3%).
- Designing interdisciplinary learning experiences (GR:4%, SK:8%, CZ:0%, SP:0%, Average:3%) in terms of (i) having to balance art and programming, (ii) ICT educators not having the expertise in other subjects, e.g. music, and (iii) educators that need to understand the objectives of both subjects (ER and Arts).

It is worth mentioning that other challenges reported were broader and derived from the participants' experience of applying ER. The top three reported were:

- School management issues (GR:16%, SK:9%, CZ:23%, SP:26%, Average:19%) in terms of (i) limited actual classroom time, (ii) oversized classes, (iii) burning out of educators by having to teach in more than one school and/or having to teach in many classes, and (iv) providing limited financial resources for technology/materials.
- Student issues (GR:14%, SK:12.0%, CZ:8%, SP:11%, Average:11%) in terms of (i) triggering students' focus, (ii) increasing students' engagement, and (iii) students lacking ICT and programming skills.
- Technical issues (GR:4%, SK:14%, CZ:8%, SP:5%, Average:8%) in terms of (i) appropriate robotic technologies availability, (ii) ICT malfunction, and (iii) robotic components' malfunction.

RQ2: How do educators design ER activities to cultivate their students' CT, what challenges do they face, and what support do they require?

While the participants reported their experience or ideas for designing ER activities to cultivate students' CT skills, our main observation was perceiving CT as a problem-solving process and associating it directly with programming to cultivate algorithmic thinking. In our study, apart from the participants (GR:13%, SK:2%, CZ:5%, SP:0%, Average:5%) who declared no CT experience, the others who claimed to have CT experience consistently described a problem-solving and/or algorithmic thinking process. Although they described activities that cultivated various CT skills, most did not use terms such as abstraction, decomposition, evaluation, etc. However, analysing data regarding CT skills, we identified the following trends:

CT conceptualisation (GR:40%, SK:9%, CZ:37%, SP:42%, Average:32%) in terms of (i) problem-solving activities and (ii) CT conception.

CT Algorithmic Thinking (GR:17%, SK:56%, CZ:8%, SP:42%, Average:31%) in terms of (i) input/output data, (ii) algorithmic structure (sequence, selection and iteration), and (iii) debugging and optimisation.

CT Data representation (GR:10%, SK:9%, CZ:5%, SP:17%, Average:10%) in terms of either data storage or process.

CT Pattern recognition (GR:13%, SK:11%, CZ:17%, SP:0%, Average:10%) in terms of using (i) geometric figures as patterns and (ii) colours as patterns.

CT Decomposition (GR:3%, SK:13%, CZ:0%, SP:0%, Average:4%) in terms of analysis.

CT Abstraction (GR:3%, SK:0%, CZ:0%, SP:0%, Average:1%) in terms of filtering out information.

Regarding the challenges participants faced when designing ER activities, the top three reported involved the following issues:

Designing and enacting ER activities (GR:46%, SK:9%, CZ:36%, SP:42%, Average:33%) in terms of (i) accommodating students' ICT and programming skills, (ii) the workload required from educators, (iii) choosing appropriate robotic technologies and (iv) availability of digital resources, i.e. simulators or programming environments.

The educational context (GR:23%, SK:14%, CZ:20%, SP:17%, Average:19%) in terms of the school management not providing (i) enough time to enact ER activities and (ii) enough money for acquiring and maintaining robotic technologies.

Student issues (GR:15%, SK:49%, CZ:7%, SP:0%, Average:18%) in terms of (i) increasing students' engagement, (ii) students lacking ICT and programming skills, and (iii) students not having the ability to follow instructions.

Lastly, the top three issues regarding the support that participants required were the following:

Educational context (GR:47%, SK:18%, CZ:39%, SP:29%, Average:33%) in terms of (i) having a supportive school management, (ii) achieving interdisciplinary collaboration, (iii) having adequate training, and (iv) nurturing an educational community.

Learning content (GR:25%, SK:25%, CZ:28%, SP:17%, Average:24%) in terms of (i) having learning materials such as video tutorials, and most importantly (ii) a repository providing exemplar activities and integrating a community platform for content and human resources, i.e., for sharing designs and collaborating with peers.

Design issues (GR:16%, SK:35%, CZ:22%, SP:14%, Average:22%) in terms of following an adequate design methodology.

Conclusions and Discussion

This paper presents a study conducted in the context of the Erasmus+ "FERTILE" project. We explored European ICT and Arts educators' design ideas and views on their challenges and the support they need to evolve their practices towards an interdisciplinary approach to Robotics and Arts in a blended learning context aiming to cultivate their students' CT skills.

Regarding the *interdisciplinarity between Arts and Robotics*, the findings reveal that educators had several creative design ideas for interdisciplinary activities, allowing us to categorise the following activity types (i) program robots to perform Art, (ii) program robots to create Art, and (iii) create artful robots to perform Art, that may be incorporated into an effective design methodology.

In this line, the challenges reported highlight the need to support teachers towards: (i) achieving interdisciplinary collaboration, (ii) dealing with curricula lacking an interdisciplinary approach, and (iii) designing interdisciplinary learning experiences. The "FERTILE" project aims to support the co-design of interdisciplinary learning experiences through a design methodology that enables ICT and Arts educators to converge their design practices towards cultivating CT. It also aims to support educators' collaboration in terms of their mindset and practicalities, such as time or place restrictions, through an online community that brings educators together and supports them in co-designing through a particular methodology.

Regarding the participants' *design ideas for cultivating their students' CT skills*, the findings revealed that most educators perceived CT as a problem-solving process. This finding complements Bower et al. (2017) and Fessakis & Prantsoudi (2019), who reported the same misconception. Also, Bower et al. (2017) raised concerns about educators' CT pedagogical capabilities and suggested adequate training. However, the design ideas proposed allowed us to extract activities promoting CT skills that may be incorporated into an effective design methodology.

Furthermore, the challenges reported in designing and enacting ER activities allowed us to infer the usefulness of a design methodology towards scaffolding educators considering CT cultivation while designing user-centred learning experiences. Noting the participants' concern about promoting students' engagement, we anticipate exploring the potential of Arts in involving students in authentic activities.

Regarding the support the participants required to cultivate their students' CT skills, (i) the design issues indicated the added value of having a robust design methodology, (ii) the learning content indicated the added value of a repository providing exemplary designs, and (iii) the educational context indicated the added value of a community platform for educators to share design ideas and material.

All in all, we have evidence of educators' needs that should be covered through the "FERTILE" project's scheduled deliverables. Specifically, we plan to develop the "FERTILE" design methodology to scaffold educators to collaboratively design interdisciplinary activities of Arts and Robotics. Also, the need for supporting educators' collaboration and for a repository with exemplary designs will guide our efforts to develop the "FERTILE" community platform as a meeting point for educators. Last but not least, educators' need for training to achieve sufficient capabilities for designing and enacting interdisciplinary projects cultivating CT skills will be integrated into the "FERTILE" training as a series of multiplier events realised in all the project partners' countries to train educators in the "FERTILE" design methodology.

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