Cultivating Computational Thinking through the integration of Art and Educational Robotics

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Abstract

This paper introduces the interdisciplinary approach integrated into the FERTILE Design Methodology (FDM) that blends Educational Robotics (ER) and Arts to cultivate computational thinking (CT) skills in a blended learning context. The paper demonstrates how ER and Arts can be combined to create interdisciplinary learning experiences through the presentation of two exemplar projects. Both projects guide students through a series of five (5) steps—Understanding the Challenge, Generating Ideas, Formulating the Solution, Creating the Solution, and Evaluating the Solution—ensuring the integration of both disciplines while fostering CT skills cultivation such as abstraction, decomposition, pattern recognition, algorithmic thinking, and evaluation. Insights from educators involved in designing and implementing these projects highlight the methodology's potential to promote interdisciplinary collaboration and student CT skill development. This paper provides practical guidance for educators seeking to implement Artful ER projects with their students, emphasizing the potential of interdisciplinary approaches to enrich student learning.

Keywords: computational thinking, educational robotics, interdisciplinarity, art

Introduction

Integrating computational thinking (CT) in education is increasingly recognized as essential for preparing students for the complexities of the modern world. CT equips students with critical problem-solving skills, enabling them to break down complex tasks, recognize patterns, and develop efficient solutions. These skills are not only vital for technology and engineering but are also applicable across various disciplines and real-world scenarios. Research indicates that developing CT skills enhances students' analytical abilities and prepares them for a wide range of professions (Wing, 2010; Grover & Pea, 2013). Combining educational robotics (ER) and arts offers a unique and powerful approach to enhancing CT skills. ER provides hands-on, practical experiences that make abstract CT concepts tangible and accessible (Fronza et al., 2017; Chookaew et al., 2018; Jawawi et al., 2022). Robotics activities engage students in the design, construction, and programming of robots, which helps them apply CT in real-world contexts (Bers, 2018). These activities become more engaging and creative when paired with art, fostering a deeper connection to the material. Artistic activities encourage creativity, innovation, and critical thinking, which are core components of CT (Peppler & Glosson, 2013; Vacca et al., 2021). This interdisciplinary approach encourages students to apply CT principles in innovative ways, integrating ER and Art perspectives to solve problems.

In this paper, we present exemplar interdisciplinary projects following the FERTILE Design Methodology (FDM), a structured framework that guides educators in combining ER and Arts to create a new context for cultivating students’ CT skills. Thus, the FDM aims at creating engaging learning experiences that promote deeper understanding of CT.

The exemplar interdisciplinary projects included in the paper showcase insights into how intentional and structured integration of ER and Arts can enhance students' learning experiences. Our aim is to offer valuable guidance for educators in designing and implementing interdisciplinary projects, now on entitled “Artful ER projects”, that situate CT in a new domain based on the synthesis of ER and Arts ones. Additionally, the paper provides insights from educators who designed and implemented the projects, into the effectiveness of the FDM steps in achieving the intended interdisciplinary and CT skill cultivation goals.

Promoting CT in an interdisciplinary context combining ER with Arts

ER is a valuable tool for promoting CT in students (Istikomah, 2018) as it provides a creative context that facilitates learning of basic programming principles including sequencing, algorithms, loops, generalization, decomposition, and debugging (Ching, 2023; Piedade, 2020; Souza et al., 2021). In this line, the Creative Computational Problem Solving model (CCPS) (Chevalier et al., 2020) combines two primary approaches: the structured problem-solving processes inherent in CT and the iterative, exploratory nature of creative problem-solving. The CCPS model is structured around iterative phases designed to facilitate transitions between understanding the problem, generating ideas, formulating the robot’s behavior, programming the robot’s behavior, evaluating the final solution and one more phase which describes a brief disengagement period for the problem solver (Off task behavior).

The FDM is based on the CCPS model, aiming to structure students’ activity around ER and Arts in a blended learning context and to facilitate enactment with students in real school settings. In particular, artistic expression and creative problem-solving across multiple domains such as ER and Painting or Music or Performing Arts, or Visual Arts, is promoted by integrating ER with Arts into four project categories: Programming Robots to Create Art, Programming Robots to Perform Art, Creating Artful Robots, and Programming Robots to Respond to Artful Triggers. Thus, the FDM steps—Understanding the Challenge, Generating Ideas, Formulating the Solution, Creating the Solution, and Evaluating the Solution—reflect an adaptation of the CCPS model’s iterative problem-solving phases. This ensures that students engage in a structured yet flexible framework that fosters CT skills through both ER and Arts, enhancing their overall learning experience.

For instance, in a project of the "Programming Robots to Create Art" category, students might program and construct a robot capable of creating a painting by moving a brush on a canvas. In a project of "Programming Robots to Perform Art" category students may program robots to dance alongside humans. Also, in a project of the "Creating Artful Robots" category students may emphasize on both aesthetic design and functionality, promoting creativity in robot building. Finally, in a project of the "Programming Robots to Respond to Artful Triggers" category students might program a robot to change its movements in response to music or lighting changes.

Moreover, the use of ER simulators aims at enabling students to experiment with programming by developing code, identifying errors, and refining their solutions in a controlled setting before implementation, providing students with the flexibility to practice and learn at their own pace, both in the classroom and at home.

Lastly, the FDM promotes CT skills cultivation in both ER and Art subjects in a way that facilitates enactment with students in real school settings. Educators of both disciplines, ER and Arts, design together a project to be implemented in both courses considering that students, through the various steps, must develop a common Artful-ER product/solution. They also have in mind that apart from the learning outcomes of their subject, they should cultivate CT skills. These skills act as the common language allowing educators to build a common design mindset. The skills that are currently under exploration are based on Selby and Woollard's (2013):

- *Abstraction* involves identifying the *key elements of a problem* while ignoring irrelevant details. It helps students focus on the essential components of the challenge, making it easier to understand and solve.
- *Pattern recognition* involves *identifying similarities, regularities, and recurring patterns* within the problem domain. It enables students to draw connections between elements and use these patterns to inform their solutions.
- *Decomposition* is necessary for *breaking down complex problems into smaller*, more manageable parts. This competency is crucial for tackling large projects by addressing each component individually.
- *Algorithmic thinking* is the ability to *develop step-by-step instructions or sequences of actions* to solve a problem. It focuses on creating efficient and logical solutions.
- *Evaluation* involves *assessing and analyzing a solution's effectiveness, efficiency, and quality*. It critically examines the outcomes and determines whether they meet specific objectives or criteria.

The FDM guides educators to design Artful ER projects through a structured, step-by-step process as follows (see Figure 1):

1. The first step, "Understanding the Challenge" engages students by introducing them to the project's objectives and helping them grasp the key elements of the challenge/problem they need to solve. As students need to identify the essential components of the challenge, approaching it from both the ER and Arts perspectives, abstraction and decomposition are CT skills that are cultivated in this and the next step. In some cases, pattern recognition is a skill that may also be cultivated for understanding particular challenges, including identifying a pattern.
2. In the second step, "Generating Ideas" students brainstorm and develop initial ideas related to the challenges identified in the previous step, stimulating their creativity and problem-solving skills through hands-on practice and simulations.
3. The third step, "Formulating the Solution" involves detailed planning and algorithm development, ensuring students have a clear roadmap for implementing their ideas from both the ER and Arts perspectives. Algorithmic thinking is emphasized during the Formulating and Creating the Solution steps, where students design, construct and program solutions, following their ideas generated in the previous step.
4. During the fourth step, "Creating the Solution" students bring their designs to life by constructing, programming and synthesizing the final product of the project as the solution to the initial challenge.
5. The final step, "Evaluating the Solution" allows students to present their solution, receive feedback based on criteria that emerge from the previous steps, and reflect on their work and that of their peers. Evaluation is an ongoing process through the project implementation that cultivates students' evaluation skills, with students continuously testing and refining their ideas/solutions based on feedback and performance assessments.

As described above, the FDM steps help students cultivate a set of CT skills that are applicable across both Art and ER disciplines, as well as in real-world scenarios.

Below, two case studies of exemplar Artful ER projects based on the FDM are presented and discussed.

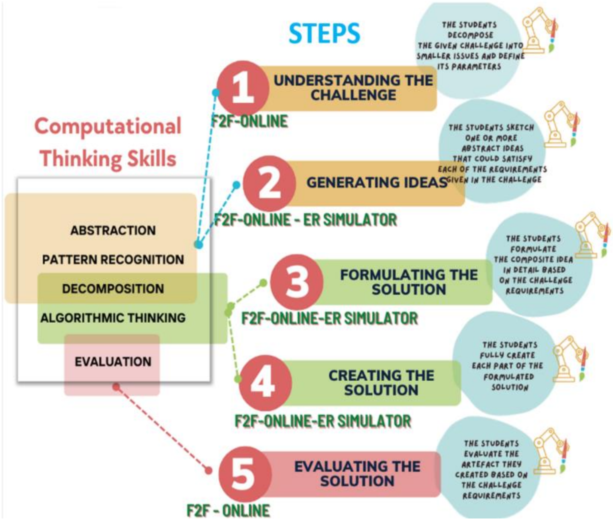

Figure 1. The CT skills that students cultivate through the FDM steps

Case Study 1: The "RoboAnimation" Artful-ER project combining ER and Animation

This project draws on a fundamental principle in animation that enhances the impact and realism of a character's actions by creating a sense of anticipation. This principle builds up tension or expectation before a significant action, engaging the audience and increasing emotion in the scene.

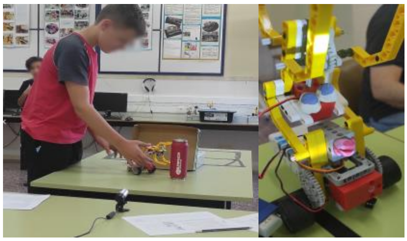

Image 1. Students engage in stop-motion activity during the "Generating Ideas" step

The challenge: To initiate the learning process, the teacher prompts students to actively engage in storytelling activities centered around a robot character.

As a challenge, the teacher provides an initial story framework, and students are tasked with developing this story further while ensuring that the main goal—programming the robot to move with anticipation—is met. For this, they must construct a robot to serve as the main character and program its anticipation-based movements. Students construct the robot hero based on its characteristics, generate ideas to develop the story, and, if necessary, set up an appropriate scene to bring their story to life.

The project falls under the category of "programming robots to perform art" targeting upper primary students. The total duration of the project is 7 hours, during which students engage in visual arts, particularly animation, to learn about speed, movement, and pause, as basic elements of anticipation. Regarding ER, students focus on constructing a robot featuring one or two motors and programming it to control direction and speed. During the project implementation, we used the NEZHA Inventor's kit for Micro:bit, with Makecode for Micro:bit serving as both the programming environment and the simulator. The construction elements included actuators such as two motors and one servo, whilst no sensors required. The project could be expanded for secondary education by incorporating other robotic platforms such as Arduino. In this case, students could take on additional challenges such as designing and building custom robot components or incorporating sensors to enhance interactivity. The storytelling and performance elements can also be adapted to suit the interests, knowledge and skills of students, potentially integrating aspects of digital storytelling.

Students follow the project steps to reach a solution to the challenge proposed (see also Table 1 for more details):

In the **Understanding the Challenge (UND)** step, the teacher presents the challenge and its objectives to the students introducing them to an initial story featuring a robot-hero with anticipation movements. The students identify key patterns and underlying concepts to understand the context and prepare for the challenge.

Then, in the **Generating Ideas (GEN)** step, the students brainstorm and develop initial ideas for their robot-hero. In the ER class, they practice with robot construction and stop-motion animation to apply anticipation techniques. In the Arts class, they practice storytelling and create visual elements for their project.

Next, in the **Formulating the Solution (FORM)** step, the students formulate detailed plans and algorithms for their projects. They create step-by-step instructions to solve smaller tasks, ensuring their robot's behavior aligns with the story. They select materials and plan the construction of the story scene, developing a clear roadmap for implementation.

Next, in the **Creating the Solution (CRE)** step, the students implement their designs, constructing the physical robot and setting up the scene as planned. They program the robot themselves using the instructions they developed earlier and make necessary adjustments to ensure correct execution. This hands-on phase allows them to transform their plans into tangible outcomes.

Evaluating the Solution (EVA) In the final step, students discuss, test and refine their solution to the initial challenge fostering a deeper understanding and improvement of their projects.

Table 1. Steps and CT Skills corresponding cultivated during the "RoboAnimation" project

The RoboAnimation Project				
FDM STEPS	**Arts**	**Robotics**	**CT skills cultivated**	
			Arts	**ER**
STEP 1: Understan	The students analyze the initial story featuring a robot hero, describing the robot's character in	The students examine paradigms of robots, their motors, and the range of	Abstra ction, Patter	

ding the Challenge	the given story, its capabilities **(Decomposition)** and focusing on the essential elements of the story **(Abstraction)**. The students identify specific patterns in the robot-hero's movements (**Pattern recognition**) reflecting anticipation.	possible movements to be able to describe the robot-hero of their story **(Decomposition).**	n recognition Decomposition
STEP 2: Generating Ideas	The teacher introduces the students to the stop-motion environment, where they put the robot to act according to their story **(Decomposition)** employing anticipation techniques **(Pattern Recognition)** (see Image 1).	Students in groups select the materials for the construction of their robot-hero (**Decomposition)** based on the capabilities of the robot-hero (**Abstraction**). Through hands-on practice and experimentation, the students learn about the concept of speed.	Pattern recognition Abstraction Decomposition
	Inspired by the activities with stop motion, students propose solutions to meet the challenge's requirements **(Decomposition).**		
STEP 3: Formulating the Solution	The students provide a verbal description of a) the movements that the robot will perform and the corresponding sequence of instructions in natural language, and b) the decoration plans for the robot (if applicable) **(Algorithmic Thinking, Decomposition).** After that they program the robot's behavior in the simulator **(Algorithmic Thinking).**	The students search for materials that are suitable for constructing the scene of the story, identify objects that are of appropriate shape and size for the robot to interact with **(Decomposition),** and formulate clear instructions for the robot's actions **(Algorithmic Thinking).**	Decomposition, Algorithmic thinking
STEP 4: Creating the Solution	The students program the physical robot, and make various accommodations **(Algorithmic Thinking).**	Students use various materials to set up the scene as they decided in the previous step **(Algorithmic Thinking).**	Algorithmic thinking
STEP 5: Evaluating the solution	Students present their final story and, in turn, try to guess their classmates' stories according to the robot's behavior. They discuss the process and evaluate their work and the work of others. Depending on the final result, they return to a previous phase to make appropriate corrections **(Evaluation).**		Evaluation

Case Study 2: The "Travel to Mars" Artful-ER project combining ER and Theatre

The challenge: Through a role-playing game, students engage in "traveling" to Mars to carry out a mission. This mission aims to collect evidence about a rover that landed on Mars some months ago but no longer sends a signal. The students will be the crew members, and the robots will be the spaceship engines.

This project falls under the category of "programming robots to perform art" targeting lower primary students. The project lasted 6 hours and Beebots was the robotic technology used. This project could also be implemented in upper primary classes with another technology of pre-built robots, such as Edison or Thymio, which require higher programming skills. It could also be implemented in secondary education with robot engines built by the students, such as Arduino, Micro:bit, Lego Spike, etc. In any case, the performance part would have to be differentiated to meet the needs/interests of the students.

Through the ER and Theatre classes, students will prepare to (a) simulate the trip going to Mars, (b) get evidence from the lost contact rover, and (c) then, when returning to Earth, analyze the evidence found and describe the trip experience.

Image 2: Travel to Mars project

The solution to the challenge is accomplished by following the project steps as follows (see also Table 2 for more details):

In the **Understanding the Challenge (UND)** step, the students discuss with the teachers the challenge of the project. They elaborate on the key elements of the challenge, aiming to identify sub-challenges, such as their role as crew members and the role of the robots in the story. In each subject (ER and Arts), they concentrate on the main tasks they have to do.

In the **Generating Ideas (GEN)** step, the students break down the tasks, brainstorm, and provide ideas about their accomplishment. In the ER class, they practice small missions with the robot simulator, and in the Theatre class, they get engaged with costume decoration ideas.

In the **Formulating the Solution (FORM)** step, the students experiment with solutions for the movements of crew members and robots. They create instructions to solve the smaller tasks.

In the **Creating the Solution (CRE)** step, the students try to find the optimum solution, apply it to accomplish the challenge, and make possible corrections. They travel to Mars, collect the evidence and return back to Earth.

In the **Evaluating the Solution (EVA)** step, using specific criteria, the students evaluate their performance as crew members and robots' performance as engines. They also reflect on the strong and the weak aspects of the mission.

Table 2. Steps and corresponding CT Skills cultivated during the "Travel to Mars" project

FDM STEPS	Arts	Robotics	CT skills cultivated	
			Arts	ER
STEP 1:		The students focus on the role of the robots as spaceship	Abstraction Decomposition	

Understanding the Challenge	The students focus on their role as crew members (**Abstraction).** They distinguish the movement of their bodies according to whether they are on Earth or Mars **(Decomposition).** They simulate their movement in different weather conditions on every planet (**Pattern Recognition).**	engines (**Abstraction).** They consider various aspects related to robots (Beebots) acting as spaceship engines (movements, programming, synchronization with the crew members) (**Decomposition).**	Pattern Recognition	
STEP 2: Generating Ideas	Break down the challenge and provide ideas for specific aspects, such as team symbols, decorations for their "costumes," etc. **(Decomposition)**. The students provide ideas for small artifacts related to these aspects (**Pattern Recognition).**	Analyze the robots' movements (**Decomposition).** and practice with the simulator through small missions (**Algorithmic Thinking**).	Decomposition Pattern Recognition	 Algorithmic Thinking
STEP 3: Formulating the Solution	The students experiment with instructions for the crew members' movements (**Algorithmic Thinking**). Do small flight tests breaking down the crew members' movements **(Decomposition).**	Students practice with the physical robots to test the take-off and landing of the engines. They give instructions to the robots to move and spin (**Algorithmic Thinking**). They discuss with the teacher the concept of scale to compare their movements in steps to the robots' ones **(Abstraction).** To measure and correlate the scale, the students stand up and try to walk next to the robot**(Decomposition).**	Algorithmic Thinking Decomposition Decomposition	 Abstraction
STEP 4: Creating the Solution	Students try on the costumes and do flight tests deciding on the most efficient way for their movements **(Algorithmic Thinking).**	Students create a step-to-step solution for robots' moving **(Algorithmic Thinking)** and find the most efficient way to synchronize human steps with robot steps.	Algorithmic Thinking Decomposition	
	Students solve the challenge by following the instructions they decided on **(Algorithmic Thinking)**, completing the trip from Earth to Mars and from Mars to Earth, and gathering the possible evidence. During the trip, they address any problems that arise regarding the members of the spaceship and the "engines" (**Decomposition).**			
STEP 5: Evaluating the Solution	Students evaluate the compliance of the evidence found with the mission. They reflect on their experience through an interview with	Students assess whether the robots acted properly during the mission **(Evaluation).** They use a star rating worksheet to evaluate programming, synchronization	Evaluation	

	the art teacher acting as a journalist **(Evaluation).**	with the other engines and their movements.	

Educators' insights from the projects' design and implementation

To explore educators' experiences with the two Artful ER projects, we gathered insights from five educators—three involved in the 'RoboAnimation' Project (E1–E3) and two in the 'Travel to Mars' Project (E4–E5) (see Table 3). Using an instrument with three closed-ended and three open-ended questions, we collected initial evidence at the end of both projects. The closed-ended questions explore educators' perceptions of how well the FDM facilitated the design and implementation (see Table 3), while the open-ended questions aim to gain deeper insights into potential challenges, successes, and improvements experienced. (**Question 1:** "*How did you find useful designing the project by a) following the particular steps' sequencing, and b) designing activities for each step?*", **Question 2:** "*Since the FDM aims to cultivate CT through the interdisciplinarity of Art and ER in a blended learning context, suggest changes/improvements in this direction.*", **Question 3:** "*What would you change in the Artful ER project design after the implementation experience?*"

Table 3. Educators' perceptions of how well the FDM steps facilitate the design and implementation of Artful ER projects

Close-ended questions	Project 1			Project 2	
	E1	E2	E3	E4	E5
Breaking down each step into individual activities was helpful for designing students' involvement in the project	5	5	5	4	5
Designing together activities for cultivating particular CT skills promoted mutual understanding of the disciplines involved.	5	5	5	5	5
The FDM supported me in understanding how to cultivate CT skills through the project.	5	5	4	5	5

The three closed-ended questions revealed high satisfaction among the educators regarding the FDM's effectiveness in breaking down steps into individual activities, promoting mutual understanding between disciplines, and supporting educators in designing activities for cultivating CT skills. Most educators gave the highest score of 5. This indicates that the structured approach of the FDM was well-received and considered effective in supporting educators in designing interdisciplinary experiences for their students.

The open-ended questions provided additional evidence. Educators appreciated the structured sequence of steps, noting that it helped them stay focused and align activities with the project's goals. Additionally, they highlighted the importance of interdisciplinary activities in fostering CT skills. However, they also indicated areas for improvement, particularly the need for clearer guidelines for delineating activities and matching them to CT skills. Educators suggested that while the FDM is flexible and adaptable, providing detailed descriptions and examples could enhance its usability. This feedback can guide further refinements to the methodology, ensuring it meets the diverse needs of educators and students across various educational settings.

Discussion

This paper presented a structured approach for developing interdisciplinary projects that blend ER and Arts to cultivate CT skills. The FDM integrates the structured problem-solving process by adjusting elements from the CCPS model to enhance students' learning experiences in a blended learning context. Two Artful-ER projects were presented to illustrate the application of the proposed approach. These projects serve as exemplars for educators to follow, demonstrating how the FDM can be implemented to connect ER and Arts, and cultivate CT. These projects' descriptions provide a pathway for educators to design interdisciplinary projects in their own educational settings. The educators who designed and implemented the projects evaluated the proposed approach as well structured and helpful in organizing courses and activities, promoting interdisciplinary collaboration for enhancing students' CT.

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