# *Extending Constructionist Media With Emerging Digital Technologies for Critical Computational Thinking*

## Emerging Technologies for Critical CT

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The rapid development of emerging technologies, such as 3D printing and Augmented Reality (AR), has opened new possibilities for learning. However, their integration into educational settings often lacks a strong pedagogical foundation. This paper explores how the extension of existing, already institutionalized and deeply studied digital expressive media, with emerging technologies can enrich computational learning and foster Critical Computational Thinking (CCT) practices. In that scope, we have extended a Logo-based programming tool with 3D printing and two game design environments with AR affordances and explored how this integration can enable a critical engagement with computational thinking activities. We present three case studies, where students engaged in design thinking projects using these enhanced tools. Our analysis reveals that emerging technologies enabled students to question computational designs, connect coding to real-world issues of their local community, and engage in iterative prototyping of multiple solutions. Findings suggest that emerging technologies, when meaningfully incorporated into constructionist tools, can foster deeper engagement with computational thinking while promoting critical reflection on digital artifacts and social issues.

*Keywords and Phrases: 3D printing, Augmented Reality, Computational Thinking, Design Thinking, Coding Tools*

## 1. Introduction

The rapid advancements in Emerging Technologies (ET), such as Augmented Reality (AR) and 3D printing, have made them accessible to the general public and part of everyday activities. Following this trend, educational organizations and stakeholders are starting to integrate them into educational practice. In the last decade, several initiatives and pedagogical agendas suggest the use of such technologies to advance the digital transformation of education (EU, 2021). However, despite the progress in equipping schools with such technologies, there is a lack of concrete pedagogy for their meaningful infusion into the current educational context. In many cases they are used in clumsy ways that do not necessarily bring added value to traditional teaching and learning and at the same time they are seen as unnecessary noise by the teachers who are not familiar with their affordances. Thus, there is need for



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more research on how existing pedagogies and learning theories could contribute to the development of new frameworks and tools that exploit emerging technologies for the transformation of teaching and learning. Constructionism theory could contribute to this transformation as it focuses on generating meanings and expressing them through interacting with the structural affordances of, mainly digital, artifacts (Kynigos, 2015; Kafai & Bruke, 2019; Holbert & Xu, 2021). Constructionist tools have long been used in education as expressive media by students who develop meanings and skills as they construct personally meaningful artifacts and share them with their peers. We suggest that, instead of using emerging technologies in the form of new tools disconnected to any pedagogy, it would have greater value to extend existing, already institutionalized and deeply studied digital expressive media, with these technologies to enrich the representation repertoire and learning opportunities afforded to the students. For instance, emerging technologies that afford connections to the real-world, such as 3D printing and Augmented Reality, can be used to enhance the computational exploration of real-world societal issues through traditional coding tools widening the opportunities they offer for expression of ideas, meaning-making and connection of computational practices to critical literacy (Lee & Soep, 2016). Such integration could contribute to the ongoing effort for combining Computational Thinking learning with Critical Thinking leading to a Critical Computational Thinking pedagogy (Lee & Soap, 2016). CCT suggests that students should use computational affordances, such as coding, to engage with social challenges and unveil biases or possible equity issues behind digital artifacts. Aiming to explore this approach we have extended three home-grown and already institutionalized constructionist tools with emerging technologies, i.e. a Logo-based 3D modeler with 3D printing and two game design tools with Augmented reality affordances. As part of a 3-year design-based research project, we have organized school interventions across 6 European countries in which students use these tools in digital Design Thinking projects. This paper discusses three intervention cases implemented in Greece, which were analyzed to identify whether and how the ET affordances of the tools enhance the development of students' Critical Computational Thinking practices.

## 2. Theoretical Background

### *2.1 Constructionist media and Critical Computational Thinking*

Constructionism puts at the center of the learning activity the creation and sharing of tangible artifacts by the students in meaningful projects, using tools and digital technologies. Starting with Papert's Logo programming language, and followed by a variety of digital tools, researchers have explored how students generate meanings and knowledge as they use expressive media to produce, change and share digital artifacts, from simulations and models to digital games and robots. As studies have shown, digital tools' affordances play an important role in the learning process of open-ended constructionist activities (Kynigos & Grizioti, 2018; Kyingos & Grizioti, 2020). Recently, attention to technology as a constructionist and exploratory medium has been renewed and given much more pertinence as individual and social computational or digital literacyWith the current need for preparing the youth for the dynamic and multi-faced world problems (UN, 2018), it is necessary to study deeper how students may develop and use Computational Thinking (CT) practices to understand, argue about and respond to current social issues. The relatively new framework of "Critical Computational Thinking - CCT" (Kafai, Proctor & Lui., 2020; Yu et. al., 2020; Lee & Soep, 2018) approaches computational thinking as a tool for children to engage with social challenges and unveil biases or possible equity issues behind technologies. Critical computational thinking emphasizes the importance of students to take both roles of critical consumers and producers with respect to digital media. In that context it promotes the creation of multimodal and transmedia products using computational thinking practices to deal with real-world societal issues and initiate social change (Yu et. al. 2020). In that context, Kafai and Proctor (2022) suggest that learners should utilize CT practices to think critically about complex and controversial issues of the world. This can be done by questioning the dominant narratives and biases in digital products, creating computational solutions for helping others or for tackling problems in their local community. For instance, Fereira's et. al. (2021) study shows the potential of serious games to enhance students' empathy towards cyberbullying by developing a critical approach to that issue as they play a relevant game. However, despite the significant theoretical elaborations on fostering the critical side of Computational Thinking, in practice, current CT tools, frameworks and curricula tend to equal computational thinking teaching and learning with CS (Kite etl. al., 2021; Tikva & Tampouris, 2021). To this end, we have chosen to extend three existing constructionist tools, originally designed for CT, with new affordances of emerging technologies and explore how this extension can enhance the socio-technical aspects of CT. In the next paragraphs we describe the rationale behind the selection of each emerging technology and the affordance design based on the current literature and needs.

### *2.2 Extending Logo-based programming with 3D printing*

Since Papert & Harel (1991) introduced Logo language and Turtle Geometry, many studies have shown the benefits of constructionist coding activities in skills development and knowledge construction. Across the years, several Logo-based environments with diverse affordances have been developed and used in K-12 education for supporting constructionist learning not only in the context of computer science and mathematics, but across the curriculum. These include, amongst others, agent-based simulation tools, such as netLogo, that integrate Logo with modelling and simulation design affordances (Wilensky, 2014) and game design and storytelling tools, such Scratch and Alice, integrating Logo programming with game and graphics design affordances (Kafai & Bruke, 2016; Werner, Campe & Denner, 2012). In the scope of exploring how coding and constructionist learning can be connected to real-world socio-scientific issues, we suggest integrating 3D printing with traditional logo-based geometry in the 3D space. This approach incorporates the benefits of tangible constructions enabled by 3D printing technology with the known value of programming and manipulating 3D models based on turtle geometry. Recent studies on the use of 3D printing for learning provide evidence that it can enhance students' motivation, knowledge, and skill development such as spatial thinking, creativity, problem-solving, and technology literacy (Lin et. al., 2023; Leinonen et. al., 2020). However, there is a need for pedagogical framing of 3D printing, especially concerning the process of imagining and constructing the models to be printed. In most relevant studies in K-12 education teachers either provide children with ready-made models or give them specific instructions on how to build them (Novak et. al. 2021; Huang & Wang, 2022), limiting their creativity and imagination of what could be printed. This happens probably due to the complexity of young learners to create and manipulate a complicated 3D printable object from scratch. Very few tools have integrated 3D printing with block-based programming, such as BeetleBlocks (Leinonen et. al. 2002), with the main focus of relevant studies being on teaching programming through 3D design and printing. To address this gap, we extended the web-based application MaLT2 (Kynigos & Grizioti, 2018) with the affordance of 3D printing, enabling the design, dynamic manipulation and printing of 3D geometrical models. Original MaLT2 version (http://etl.ppp.uoa.gr/malt2/) integrates three affordances: a) Logo-based programming of 3D models on a 3D scene b) Dynamic manipulation and animation of the created models with a sliders tools, allowing for the instant variation of the parameter values of any executed parametric procedure and c) 3D navigation with a periscopic camera in the 3D scene that allows for the examination of 3D artefacts from different angles and scales. The new 3D printing affordance of MaLT2-ext bridges the digital models that students design on the 3D scene with the properties of a physical object (Figure 1), aiming to promote activities of 3D design for tangible solutions to real-world problems.

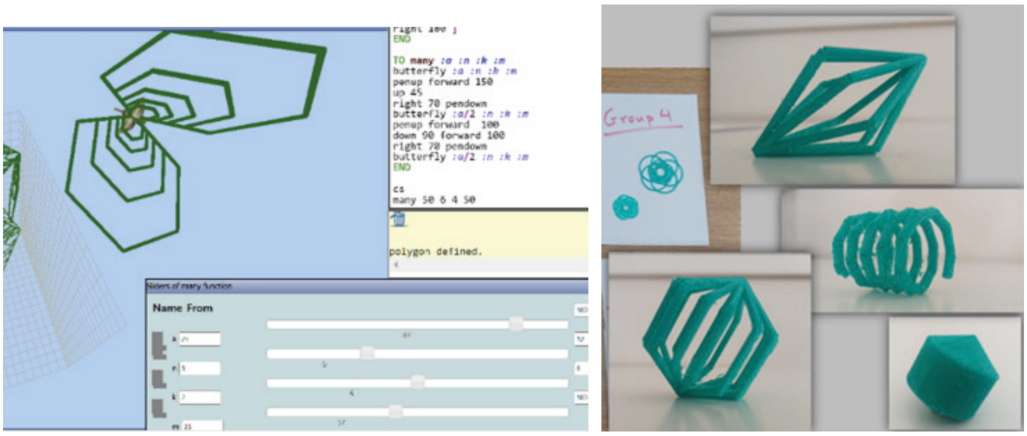


Figure 1: One the left, MaLT2-ext environment integrating Logo programming, 3D navigation and dynamic manipulation/animation, On the right: Models designed and printed with MaLT2-ext

### 2.3 *Extending constructionist game design tools with Augmented Reality*

There has been long research on using digital games as educational tools since they offer a familiar but also challenging context for students to explore new concepts and ideas. Constructionist approaches to game-based learning put game design by the students in the centre of the activity. In constructionist games learners, are involved in game design decisions and processes and become producers of their own digital media (Kafai & Bruke, 2016; Grizioti & Kynigos, 2021). Studies have shown that game design and game modding can offer a multidisciplinary and intriguing context for meaning-generation and skill development (Kynigos & Grizioti, 2020). Constructionist game design environments enable students to build, test and share their own digital game without requiring high technological knowledge. However most studies and activities with game design environments focus on the development of students' computational knowledge and skills. On the contrary, there is very limited research exploring game design in a socio-scientific context, looking at the development of skills such as empathy, critical thinking and citizenship. To that end, we employed Augmented Reality affordances to extend two constructionist game design tools aiming to enhance STEM concepts but also to place them at the service of cultivating a critical approach to game design.

#### Choice-driven simulation games with geolocation and real-world data

The first tool, called ChoiCo-Ext (Choices with Consequences-Extended), is an online application developed by Educational Technology Lab - NKUA that allows the play, design and modification of choice-driven simulation games that deal with socio-scientific issues. In ChoiCo games the players are engaged with decision making between choices with contradicting consequences to a set of societal and positivist values (Grizioti & Kynigos, 2021). ChoiCo original design (http://etl.ppp.uoa.gr/choico/ ) integrated three affordances for game design: a) a map-like design of the game scene on which the user adds static background images and points as game choices, b) visual data editing with an editable database that represents the game values and the choices' consequences and c) game rules programming with a block-based programming language. To enhance empathy and engagement with authentic problems we extended original ChoiCo tool with the affordances of Geolocation and geo-data (Figure 2). The affordance of real-time data i.e. road traffic and air pollution, affecting the game rules and parameters, allows the game designer to create a dynamic gameplay experience that changes according to real-world conditions of the game map area. This feature aims to enhance students' empathy, understanding, and authentic problem solving of the simulated issue e.g. the transportation problem in their city. The affordance of geolocation design allows students to design ChoiCo games as they move in different places and collect, manipulate and represent information from these places in their game. In that way students can discover and share issues of their local community. For example, they can design a game with points representing recycling habits in their city which can then be shared with other classmates or with students from other cities in the world.


Figure 2: ChoiCo-ext in 'game play' mode. The player keeps selecting to visit different places on the map that affect the game values (Travel time, fun, money etc) aiming these values won't cross their red lines (e.g Money < 0)

## Classification games with body and voice recognition

The second gaming tool called Sor.B.E.T-Ext (Sorting Based on Educational Technology-AR) is an on-line application that allows playing and designing classification games (Grizioti & Kynigos, 2024). With Sor.B.E.T, learners can engage in constructionist activities by playing, modifying and designing Tetris-like classification games with diverse content and complexity (Figure 3). Students can easily switch between the roles of players and designers, question the game content and express their own ideas through modding. The 'Design Mode' offers two interconnected affordances for modifying or creating new classification games, i.e. an interactive database representing the objects that fall and the categories they belong to and block-based programming for coding game settings and rules. As studies have shown playing and designing games in Sor.B.E.T can enhance students understanding of computer science and mathematical concepts such as data handling, data structures, set theory, objects' properties comparison and classes' encapsulation (Grizioti & Kynigos, 2024). Aiming to enhance communication and collaboration during gameplay but also immersion with the game topic we extended with the affordance of embodied interaction. Many studies have shown the benefits of embodied interaction with technology for deeper learning and meaning generation about complex scientific concepts by students (Weisberg & Newcombe, 2017; Kynigos et. al., 2010). In Sor.B.E.T-Ext students use their gestures as a means of categorizing objects and their voice to intervene with the game rules (e.g. 'faster' will increase the objects'velocity). This enhancement aims to improve the communication and interaction among players during the learning process, as well as to facilitate the development of strategies for classification and the interpretation of concepts.

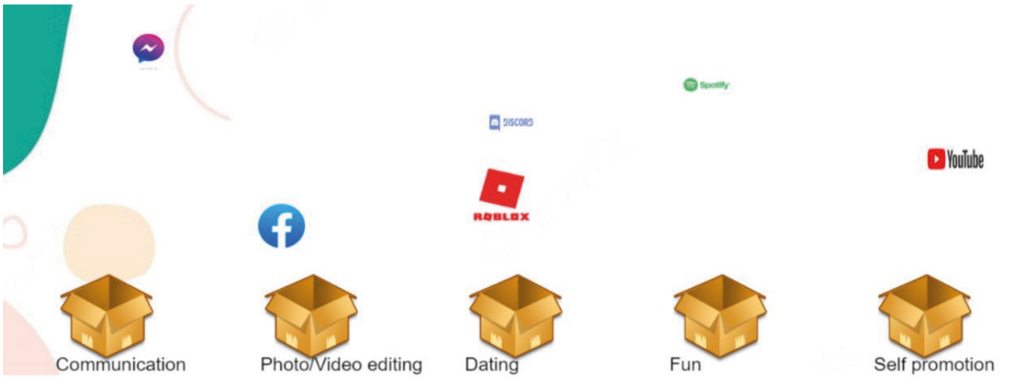


Figure 3: The "App Game" in SorBET-ext play mode. Player classifies falling Apps to categories representing the purpose of use

## 3. Methodology

Aiming to explore the pedagogical value of above emerging technologies affordances to Critical Computational Thinking, we organized 3-cycle design-based research (Barab & Squire, 2004) as part of the ExtenDT2 research project (Milrad et. al. 2023). In each cycle, partners across 6 EU countries implemented school interventions in which students used the three extended tools in Design Thinking projects in their classrooms. The DT project for each intervention was co-designed by schoolteachers and researchers using a DT activity plan template. In the projects students created a digital artifact (i.e. a game with ChoiCo/SorBET, or a 3D model in MaLT2) that would contribute to a real-world issue. Each project consisted of 5 phases, based on the ExtenDT2 DT model, i.e. "Empathize & Understand", "Define & Ideate", "Rapid prototyping & Iteration", "Sharing & Feedback", "Respond & Deliver". This paper analyzes 3 intervention cases, one with each tool, that were implemented in Greece as part of the 2nd cycle of the project, in the schoolyear 2023-2024. The 3 cases vary on the DT topic and the technology used by the students, but, since they are part of the same research, they follow the same research methodology, data collection and analysis methods that are described in the next sections.

### *3.1 Implementation Context*

The first intervention was implemented in a model high school in Athens as part of an after-school STEM club. The participants were 22 students (10 females, 12 males) aged 14-15 years. It lasted 8 hours, divided into 2 sessions. Students implemented a DT project called "Jewelry and more" in which they designed and printed

3D jewelry using MaLT2-Ext. The second intervention was implemented in an experimental high school in Athens as part of the Computer Science course. It had a duration of 8 hours splited into 4 sessions and involved 30 students aged 12-13 years. Students created a digital embodied game in SorBET-Ext addressing cyber security dangers. The game was supposed to be installed on a large screen setting (e.g. in their school or a museum) to raise awareness of cyber security issues among players. For the Discover phase, students played a game created by their teacher, called "App Game", in which they had to classify famous Apps (e.g. Facebook, Instagram) to their purpose of use (e.g. dating, news). The third intervention was implemented in a vocational school in Athens with a duration of 12 hours splited into 6 sessions. The participants were 14 students (2 females, 12 males) aged 16-22 years. Students were engaged in a DT project titled 'Entrepreneurship with ChoiCo,' in which they designed a ChoiCo-Ext game to simulate the practice of an entrepreneur. The aim of the project was to encourage vocational students to develop entrepreneurship ideas related to their specialties and interests.

### *3.2 Data Collection and Analysis*

In each study we collected various types of data, to evaluate students' interaction with the technologies and with each other during the DT projects. These included researcher observation notes, using an observation protocol, video/audio and screen recordings from 2 focus groups, interviews with the focus groups students, pre- and post-surveys, artifacts of learning, (e.g. 3D models or games prototypes, notes), and an interview with the teacher. We did a qualitative thematic analysis of the transcribed dialogues using the critical episode (Tripp, 2011) as the analysis unit. Critical incidents were used to identify events that were significant in the action and to explore them in depth using observational data (video, audio or written) primarily with interviews and reflections providing supporting or refuting evidence. we followed an abductive coding technique, in which the researcher starts with an initial coding scheme but remains open to the creation of emerging codes. For the initial coding scheme and the thematic analysis, we were based on the Critical Frame of CT by Kafai, Proctor & Lui (2020), including codes such as "critical understanding", "enacting social change", "strategies for social action", "Question the values of computational media", "design to promote awareness/activism". We also did a descriptive statistical analysis of the pre- and post-surveys to gain insights into classroom level. We first analyzed each intervention case separately and then three researchers did a retrospective analysis for the creation of the final themes.

## 4. Results

The analysis showed that the new affordances of the three constructionist tools, enabled students to develop practices and perspectives connected to the critical computational thinking paradigm. Table 1 summarizes the themes that occurred and were relevant to "Critical Computational Thinking". In the next three sections we analyze three of those themes with representative critical incidents.

| Analysis Theme | Description | Examples |
|---|---|---|
| Question the values of the given computational design | Students doubt the computational design of a given digital artifact, recognize biases of the designer and discuss possible issues | Question the usability/ printability of a given digital model (MaLT2), Disagree with the default classification of objects in SorBET |
| “Phygital” Computational Thinking | Implement Computational Thinking practices by combining the physical and the digital representations of an artifact (e.g. the digital model and the physical instance of an object) | Identify patterns in a dimond model by comparing the physical and digital artifacts, Cluster the game points (choices) based on geolocation/map features (ChoiCo) |
| Reflection based on personal values | Students express ideas about the computational design based on their personal values, background or perceptions of the given problem | Disagree that the choice “visit the hospital” should decrease money because hospitals must be public (ChoiCo) |
| Rapid prototyping and iterative development | Students are engaged in a repeated process of rapid creation of prototypes, testing, reflection and redesign | Create several prototypes of jewelry using dynamic manipulation and parametric procedures in MaLT2 |
| Connect a computational solution to local interests | Students create a computational solution with the aim of tackling an issue connected to their local community | Design a simulation game about their school facilities in ChoiCo, Design a game to raise awareness for cybersecurity in their local primary school (SorBET), Decide to print the jewelry with wooden-based filament (MaLT2) |
| Design a computational solution with empathy | Students create a computational solution by analyzing the needs of the target audience | Design the falling objects larger for elder people in a SorBET game, Ask their schoolmates and teachers about problems they have with school facilities (ChoiCo) |

Table 1: Emergent themes and examples.

### 4.1 Develop a phygital approach to CT practices with MaLT2-Ext

The affordance of 3D printing, integrated in MaLT2-Ext, gave students access to the digital and physical representations of the 3D model leading to what we coded as “phygital” CT, by combining the words physical and digital. The two representational forms led students to a deeper computational analysis that wouldn’t have happened without the printing affordance. In such cases, it was the physical artifact and its purpose of use that led them to redesign their code. It was quite common that students designed a digital model in MaLT2-ext and then realized it wouldn’t be printed correctly, or it wouldn’t result in a functional physical object for their project. This led them to apply reflect on the initial digital design and apply CT practices, such as pattern recognition between the 2 models, in order to refine the code and thus improve the physical artifact. Some groups also discussed their code’s generalizability and reusability for different objects or the model's adaptability for different printing materials. In critical incident 1 (table 2), students design printable letters for kids to stick them on their water bottles. However, they realize that a 2D 'flat' letter wouldn't be usable since it could not stick on a bottle. They explore solutions to make the digital letters 'curved', applying computational and mathematical practices. They also discussed the properties of the digital model in relation to the printing process and the usability of the final object (e.g. thickness). Their final productions are shown in Figure 4.

| # | Transcript | Codes |
|---|---|---|
| 1 | S1: Hey ! This is flat [the printed letter] It cannot stick to any bottle! It is useless! What do we do now? | Phygital CT -> Practical usage |
| 2 | S2: We have to make the letter fold like this. But it would be hard to design | |
| 3 | S1: Let's think. We have to bend these three lines. So instead of straight lines they should be something like semi-circles | Phygital CT -> Decomposition |
| 4 | S2: Like repeat 180 [forward 1 right 1] ? | Phygital CT -> Pattern recognition |
| 5 | [after they have created a bent letter]<br>S2: Yes!! That's it! [...] And if we put a variable here [shows the 180 step in the repeat] I think we can control how curved it will be! | Phygital CT -> Abstraction, Practical usage |
| 6 | S1: Would this be printed alright though? | |
| 7 | S2: If we make the lines thick enough and print it horizontally I think yes. | Phygital CT -> Engineering aspects |

Table 2: Critical Incident 1.


Figure 4: The 'curved' letters students created for the 'jewelry' project in MaLT2-ext

### 4.2 *Questioning the game data with collaborative embodied play in SorBET-AR*

The embodied interaction of SorBET-AR tool, enabled students to play simultaneously, fostering collaboration and discussions about the game content (Figure 5). As players, students expressed personal ideas about the properties of the falling objects and debated the correctness of the game classification model. This led most groups to examine the game data in a critical way (coded as 'critical data interpretation') and modify them according to their views (coded as 'reflection on personal values'). The simultaneous embodied interaction seemed to foster spontaneous expression of ideas. This is shown in critical incident 2 (table 3), where 2 students are playing the App game. In lines 1 and 5 the student spontaneously pushes the object away from the category their teammate had put to fall into and argue about their action. Also students doubt the design since the categorization model does not reflect their personal views.

This brings to the foreground different views on how the apps are used and possible biases students or the game designer may have (lines 2, 4, 7 and 8). They also used the database to modify the game objects and the classification model according to their views as shown in Figure 5.

Figure 5: Left: students interacting with SorBET-ext in play mode, Right: students editing the game using the database in design mode

| Line | Transcript | Codes |
|---|---|---|
| 1 | S3: No no Instagram is clearly for self-promotion, not for communication [push its away] | Question the values, Critical understan-ding |
| 2 | S4: Not necessarily. I don' t use it like that | |
| 3 | S5: S3 does it! And most kids do it! See it is correct! [the category box turned green] | |
| 4 | S4: Well, I disagree. The correct category should be the one it was originally designed for | Reflection based on personal values |
| 5 | S3: Facebook for dating?? No take it way from there [moves quick to grab it] | |
| 6 | S3: Oh! It was correct! But who uses Facebook for dating? Are they serious? | Question the values Critical understan-ding |
| 7 | S4: Sir! This game is wrong! We need to fix it | Question the values -> Willing to modify the design |
| 8 | S3: Or whoever made they have categorized the Apps accor-ding to how they are using them (they laugh) | Question the desig-ner's views |

Table 3: Critical incident 2.

### 4.3 Use CT to tackle local issues with geolocation in ChoiCo-AR

In the third case study, the games that students created about entrepreneurship were inspired by places or situations they discovered in their neighborhood, their school or their city by using the Geolocation and geo-data features of ChoiCo-Ext. For instance, one group used google maps satellite view together with geolocation and created a game about improving the school facilities (e.g. the restaurant, the gym etc). The game simulated the choices a student can make in the school and how these affect her/his joy, social life, money, knowledge, energy and schools' absence (Figure 6). Another group created a game about possible places for acquiring spare parts for car service, putting as a game parameter the time needed to move between places in the city (Figure 6). To calculate travel time, they used live traffic data in the game database provided by ChoiCo-AR's geolocation feature. Moreover, the analysis showed that students engaged in reflective thinking during the development of the game, aiming to make it as realistic as possible to players. This process led them to form numerous reflective questions and reason about their decisions. For example, questions like “Is there a car that is actually environmentally friendly?” (Group 2) and “I usually skip ‘gymnastics’ because we don’t have a nice gym to practice in the school” (Group 1) initiated discussions about the game topics.

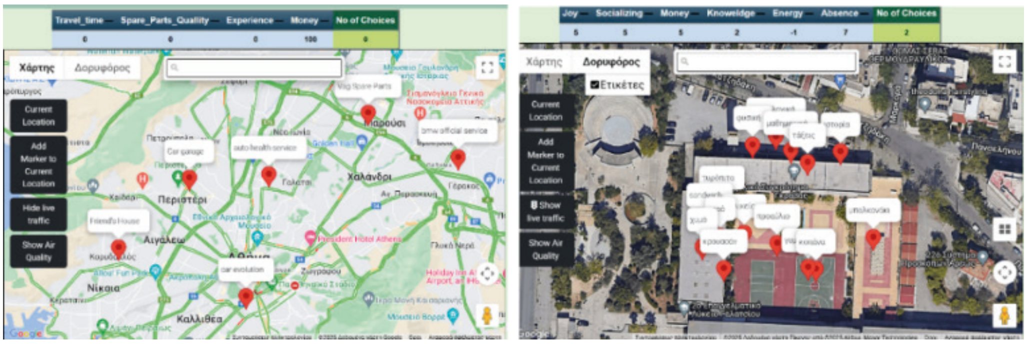


Figure 6: Two games created by students in ChoiCo-ext using geolocation, google map and geo-data features

## 5. Discussion and Conclusion

The results show that the integration of emerging technologies’ affordances to existing constructionist tools can provide new opportunities for Computational Thinking learning that were not possible before that integration. The presented 3D printing and Augmented Reality affordances allowed students to explore real-world issues and connect the computational solution to socio-scientific issues of their local or global communities. This is a key process for taking CT beyond coding or mathematics education and fostering Critical Computational Thinking development.

3D printing integrated into the MaLT2 programming modeler enabled students to use programming and CT practices for creating a useful physical object that would solve a real-world issue. In contrast to traditional Logo programming activities, in which students explore only the digital representation of the geometrical model (Kynigos & Grizioti, 2018), in this study they redesigned the model multiple times considering engineering parameters that would affect its printing and its usage as a physical object. Based on the relevant emergent analysis themes, it seems that this design incorporates the benefits of traditional logo geometry activities, e.g. iterative design, experimentation, with those of tinkering with physical material to create a useful tangible artifact (Kafai, Fields & Searle, 2014). Embodied interaction affordance of SorBET-ext allowed for collaborative play and fostered discussions about the game content. This led students to develop a critical interpretation of the game by questioning, disagreeing and changing the classification model according to their personal views. The embodied interaction in conjunction with the design affordances of SorBET (database, block-based programming) engaged students in the role of critical designers in which they used CT not only for creating a new game but also for criticizing and reflecting on the original game’s axioms and values. This process reflects the part of CCT that is related to doubting dominant narratives, recognizing possible biases and propose modifications to represent their own voices through the digital artifact (Lee & Soap, 2016). Geolocation and real-time geo-data integrated into ChoiCo, fostered students to explore and understand issues of their local community through the games they designed. In this case, students paid attention not only to the technical development of the game (e.g. programming the rules, setting the data) but also to the game content and how it will efficiently represent the selected issue, i.e. the game theme, the map representation and the information regarding the choices and consequences. Through that process students got engaged with the part of CCT that concerns the creation of multimodal artifacts to address personally relevant social issues (Margolis et, al. 2012), such as the facilities in their school or the traffic problem in their city.

The study also had some limitations that should be considered. Analyzing three diverse technologies under a common research question and coding scheme was restricted for deeper understanding of their unique opportunities and limitations for learning. Further studies and analysis are necessary to understand the added pedagogical value of each technology to Computational Thinking and to knowledge development in other fields as well (e.g. mathematics, physics)

In conclusion, this paper provides some evidence that the approach of integrating emerging technologies' features to existing constructionist tools with known pedagogical value, could be beneficial in two ways. First, it can expand the ways students interact and engage with computational technology providing new representations of complex concepts (e.g. the 3D models) and means for self-expression. Second with the connection of computational processes (e.g. coding, game design) to real-world situations (e.g. printed artifacts, geolocation) it can widen the possible Critical CT activities, apart from cognitive and situated ones (Kafai, Proctor & Lui, 2020), that can be designed with these tools.

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