Integrating Computational Thinking and Data Science: The case of modding classification games

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Abstract
Even though working with data is as important as coding for understanding and dealing with complex problems across multiple fields, it has received very little attention in the context of Computational Thinking. This paper discusses an approach for bridging the gap between Computational Thinking with Data Science by employing and studying classification as a higher order thinking process that connects the two. To achieve that, we designed and developed an online constructionist gaming tool called SorBET which integrates coding and database design enabling students to interpret, organize, and analyze data through game play and game design. The paper presents and discusses the results of a pilot study that aimed to investigate the data practices secondary students develop through playing and modifying SorBET games, and to determine the impact of game modding on student critical engagement with CT. According to the results, students developed and used certain data practices such as data interpretation and data model design to become better players or to design an interesting classification game. Moreover, game modding process motivated students to question the original games' content, leading them to develop a critical stance towards the game data model and representations.

Introduction
It has now been more than a decade since researchers and educators seem to increasingly agree on the argument that Computational Thinking (CT) is a literacy-oriented 21st-century skill that all students should develop across the curriculum (Wing, 2009; Li et. al., 2020, Jakob & Warschauer, 2018). As such, CT should not be limited to just another programming paradigm, but rather should involve a range of practices and concepts such as simulation design and data handling, spanning the field of computational problem-solving. In practice, however, there are very limited studies and frameworks exploring CT beyond tasks and tools oriented narrowly towards programming (Kite et. al., 2021; Tikva & Tampouris, 2021). An important aspect of CT that has gained less attention, in both practice and research, is that of data science. In this paper, we argue along with others that working with data is as important as coding for understanding and dealing with complex problems across multiple fields, such as physics, biology, history, and mathematics (Basu et al, 2020; Holbert & Xu, 2021). Working with data involves skills and practices concerning data collection, data analysis, organization and comparison, data visualization and interpretation of data representations.

To date, there has been several digital media designed with the educational intent to support student engagement with programming, stemming from the early work of Seymour Papert (1980) all the way through the present time (Kafai & Burke, 2016, Kynigos & Grizioti, 2018). Likewise, there has been an albeit a smaller number of digital media to support meaning-making in data handling mainly connected to statistical thinking (Tinkerplots, Bakker & Derry, 2011 Fathom, Biehler et al, 2012, Paparistodemou et al, 2008, Rubin & Hammerman, 2006). However, these two fields have been perceived as somewhat disconnected and there has not been much interest in designing a digital medium where data science and programming co-exist in some kind of meaningful way. We thus argue that the development of tools and approaches for engaging students with data science in the context of CT and its programming element remains a challenge and the relevant studies are still quite limited.

In this paper, we attempt to contribute to this challenge by employing and studying *classification* as a higher-order thinking process that can be the glue between Computational Thinking and Data Science due to its strong connection to information handling, evaluation and manipulation. Classification refers to the process of categorizing objects or substances into classes or sets according to commonly recognized properties (Cao et al., 2017; Owen & Barnes, 2019). The ability to classify and understand classification however goes much deeper than simple categorizing. Many researchers, describe it as a logical-mathematical operation necessary for developing formal operational thinking (Inhelder & Piaget, 1964; Adey & Shayer1994). Yet, in education its importance has been relatively downplayed, focusing mainly on its basic operations in elementary schooling, leaving aside its more complex practices, such as abstraction, generalization, logical operations, design of the classification model and categories discrimination which are also central to computational thinking and data science (Milne, 2007).

So, we asked ourselves, can the understanding of and engagement with classification plays a role in a more precise and yet broad understanding of CT as literacy? To this end, we designed and developed an online constructionist gaming tool which we called Sor.B.E.T (Sorting Based on Educational Technology). SorBET is an authoring system which affords its users the role of a prosumer, i.e., the play and design of Tetris-like classification games by integrating coding and database design (available at: http://etl.ppp.uoa.gr/sorbet/). SorBET, was designed for its users to collaboratively play, modify and design classification games of different scientific topics. The playing of classification games aims to provide a familiar and intriguing context for students to interpret, organize and analyze different kinds of data. The game-modding feature aims to engage students with processes of data handling, modelling and analysis, through self-expression and tinkering with a SorBET game. To gain insight into the Computational Thinking and Data Science strategies students may develop through that approach, we organized a pilot study with secondary education students who played and modified two SorBET games each with distinct content. The aim was to answer the following research questions:

a) Which Data Practices do students apply and develop in the context of Computational Thinking while they play and modify two classification games on diverse scientific topics in SorBET?
b) Whether and how game modding of classification games can foster student critical engagement with CT in different subjects?

Theoretical Framework

The Data side of Computational Thinking

Computational Thinking refers to the ability to apply concepts, practices and perspectives that come from computer science, to solve problems and understand human behaviour in a wide range of domains and everyday life. Many researchers have stressed that CT is a new kind of literacy that goes beyond coding and involves different kinds of computational practices and behaviours (Wing, 2006; Grover & Pea, 2018). Despite the extended theoretical elaborations on Computational Thinking over the last decade, recent meta-reviews show that there is a significant mismatch between its theoretical conceptualizations and its practical operationalizations (Kite et. al., 2021; Tikva & Tampouris, 2021; Tang et. al. 2020). In practice, current CT research and approaches tend to approach computational thinking solely with programming, leaving aside other important aspects of computational problem solving such as data science and simulation design. This tendency constrains CT to subject-specific implementations instead of an integrated computational literacy as was initially envisioned, necessary for transforming 21st-century education (Manilla et. al, 2014; Fessakis et. al., 2018). Recently researchers have claimed that more focus needs to be given to transforming Computational Thinking from a programming-oriented to a literacy-oriented approach, by means of extending the computational tools and the subjects it is being applied.

One suggested approach is to support the creation of digital artefacts with multiple affordances beyond or in conjunction with coding including tools for data analysis and representation (Kite et al, 2021; Basu et al, 2020). Understanding, managing, and representing data computationally are necessary processes for dealing with complex problems in many different fields. Moreover, the recent EU digital competence framework for citizens highlights information and data literacy as one of the five main competence areas for all 21st-century citizens (Vuorikari et. al., 2022). This involves amongst others the ability to store, manage and organize digital data, information and content that in turn requires classification skills and operations. According to Mike et.al. (2022), the integration of computational thinking with data science can improve children's understanding of domain knowledge and engagement with real-world problems. As they mention, dealing with big data requires computational thinking skills, like abstraction and pattern recognition, and vice versa, working with real-life data can reveal the potential of computational thinking for dealing with important real-world problems.

It seems that there is high value in connecting data science with computational thinking. However very few CT frameworks include data-related practices (Tikva & Tampouris, 2021) and the relevant empirical studies are even more limited (Kite et. al., 2021). This results in a lack of knowledge on how students may understand, develop and apply these practices. In 2015 Weintrop et. al. (2015) presented a CT framework for Math and Science Education (CT-MS) that mentions "Data Practices" as one of the core elements of computational thinking. These practices include Collecting Data, Creating Data, Manipulating Data, Analyzing Data and Visualizing Data. However, only recent empirical studies, like those of Basu et.al. (2020) and Holbert & Xu (2021), have started to explore data-oriented approaches in the context of computational thinking showing the great potential of data analysis, data editing and data visualization in both CT and domain knowledge development. The studies also highlight the importance of approaching and assessing data learning in relatable contexts for children, such as digital games, rather than focusing only on formal data knowledge. Thus, the research challenge is now to identify which data science concepts and practices can be connected with CT and become a learning object in K-12 and which computational media can foster their development in a relatable and accessible context for young students.

Classification and data-related practices

Classification is the process of categorizing objects or substances into classes or sets according to commonly recognized properties (Micklo, 1995). Even though it is usually connected to the early stages of children's development through its simplest form, it can also be a complex mental process that involves higher-order practices adjacent to both programming and data science. Advanced classification operations include, amongst others, comparison of objects and data, discrimination between properties, and generalization of characteristics from classes, (Milne, 2007). These processes are connected to CT practices like abstraction and pattern recognition and to data analysis practices, such as data comparison and manipulation. Moreover, classification is a process that can be applied for enhancing student understanding of scientific concepts across different domains. For instance, one study found that a combination of classification activities in science education enabled students to understand the differences between the concepts of object and matter, something that was difficult for them in traditional activities (Krnel, Glažar, & Watson, R, 2003). However, in practice, most of the existing educational digital tools and activities that engage students with classification, focus only on its basic operations usually through simplified closed tasks that address early learning stages (Owen & Barnes, 2019). As a result, there is limited knowledge of how more advanced classification activities could contribute to student engagement with data-related concepts and practices across different subject areas.

Playing and modding half-baked games for computational learning

According to researchers, digital games as learning tools offer a familiar but also challenging context for students to experiment with ideas and develop new meanings through productive failure and problem-solving. They lower the stakes of what is expected of them, allowing them to make mistakes, express themselves and be deeply engaged with the game flow (Bado, 2022; Gee, 2003). Thus, a common approach to the development of Computational Thinking is for students to design and program digital games (Kafai & Bruke, 2016). However, as studies have shown, in practice, the development of a functional digital game from scratch can be a quite demanding process resulting in low-level artefacts, focus on technical and irrelevant issues, disappointment and disorientation from the original learning goals (Denner et. al. 2012).

In this paper, we discuss SorBET as a tool to support children's progressive engagement with CT and Data Science practices through *game modding*. SorBET is designed to afford game modding, i.e. to invite students to play a game and then modify parts of it according to their own ideas about its content and rules (Sotamaa, 2010). In contrast to traditional game editing activities, students are not asked to make certain modifications pre-defined by the educator, but rather they are encouraged to think about possible changes while playing the game based on what they don't like or disagree with. Modding, by its nature, is based on questioning the original game content through several hours of gameplay and expressing personal ideas through the new version.

Even though modding originally comes from the world of gamers, in recent years it has been transformed into a promising pedagogical approach for scaffolding student engagement with complex learning content and with computational learning. Studies have shown that game modding activity can foster the progressive development of children's higher-order skills such as computational thinking, system analysis and design thinking (El Nasr & Smith, 2006; Grizioti & Kynigos, 2021; Örnekoğlu et. al., 2021). Our technique for structuring meaningful game modding activities with an educational intent is the development and use of what we have termed *"half-baked games"* (Kynigos & Yiannoutsou, 2018; Kynigos & Grizioti, 2020). Designing half-baked games is a kind of didactical engineering process where students are given intentionally fallible games and challenged to doubt and question the game values and axioms and to modify the given games so that they embed their own ideas. Half-baked games are fully functional in technical terms, but they have either questionable values or logical or conceptual “bugs” engineered into their content or rules which disrupt the expected game flow or meaning.

SorBET: A constructionist gaming system integrating Data Science and CT

To address the aforementioned challenge of integrating Data Science and CT, we developed a Constructionist Authoring System called SorBET (Sorting Based on Educational Technology) that allows the play, design, and modification of Tetris-like classification games (http://etl.ppp.uoa.gr/sorbet). The SorBET idea stemmed from a full-body game developed over ten years ago called “Sorter” in which players, using their body’s shadow, ‘pushed’ falling coloured objects to dump into the respective container at the bottom of the screen (Karadimitriou K., & Roussou, 2011; Kynigos, Smyrnaiou & Roussou, 2010). The idea we had at our Lab was to generalize the sorter game and make it authorable so that the user can choose what these objects represent and what the category containers signify. Originally we built SorBET prototypes with the help of two of our masters students (Giama, 2020; Nikolaou, 2022). We then proceeded to transform “Sorter” into a web-based stand-alone and open-source application that can seamlessly run in any device with access to the internet. We also extended its affordances with the feature of end-user game design allowing the modification of the game content, i.e., what is classified and in what categories, and rules, e.g., falling speed, density, times each object appears.

In tetris, a player clicks to rotate and horizontally displace objects falling of the top of the screen so that they fit on top of other objects accruing at the bottom. In a SorBET game the player scores by ‘pushing’ elements falling off the top of the screen to drop into the right category box at the bottom (Figure 1). ‘Pushing’ elements can be done by picking and dragging on a screen and will be extended to also include gesture interaction. The gameplay builds on quick decision-making, pattern recognition and abstraction of the characteristics of the falling objects. When the game is over the players are informed about their decisions in the game log, which they can also download as a pdf file (Figure 2).

SorBET builds on the Constructionist approach to learning, according to which learners put concepts into use and generate powerful ideas through the processes of tinkering, sharing and discussing personally meaningful artefacts through programmable digital media (Papert, 1989; diSessa, 2001, Kynigos, 2015). Studies have shown that constructionist learning environments can be quite beneficial for computational thinking learning as a literacy that goes beyond the CS subject and across the curriculum (Dolgopolovas et. al., 2019). Thus, SorBET enables non-technical users (e.g., teachers and students) to take the role of designer and create their own classification games with high-level interconnected computational affordances (Kynigos, 2008). These affordances allow for the rapid creation or modding of classification games with diverse complexity and content covering the span of STEAM education, e.g. from math, biology and physics, to history, arts and environmental problems.

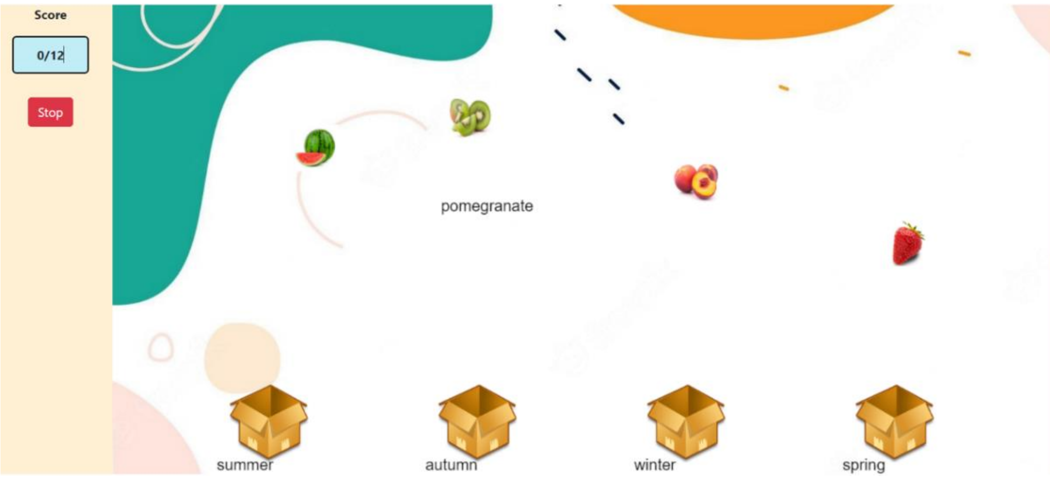

Figure 1: Screenshot of the SorBET environment in Play Mode. Player classifies falling objects (images or text) to the category boxes

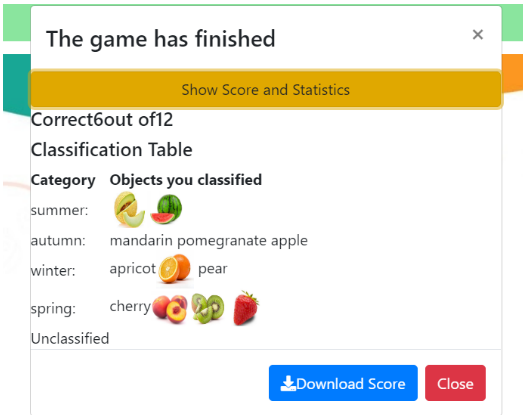

Figure 2: The score table showing how the player classified the objects

The "Design Mode" offers two interconnected affordances for modifying or creating new classification games, i.e., an interactive database and block-based programming. The database represents the objects as rows and the categories they belong to as columns (Figures 3 and 4). An object can be either an image or a text, offering multiple representations of the same concept, while in a future version, sound will be included. Each object has a number of checkboxes representing with Boolean logic whether it belongs to a category or not. The designer can select the categories each object belongs. SorBET follows the classification model of "one to many", which means that one object could be classified into one or more categories. This design decision aims to raise discussions between players about the intersections or mutual exclusions of available categories based on the object properties. This feature also enables the design of games for more complex issues with unclear, questionable classification rules, such as socio-scientific issues and wicked problems. The designer can also define the number of falling instances for each object, making an object fall more than one time in the same game.

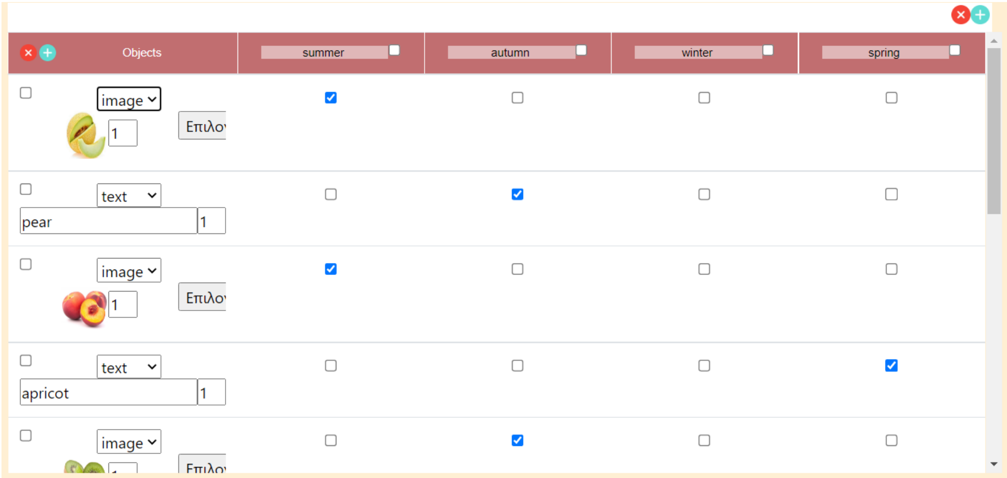

Figure 3: The SorBET database in Design Mode. The user can modify the game categories, the falling objects, their density and the categories they belong to

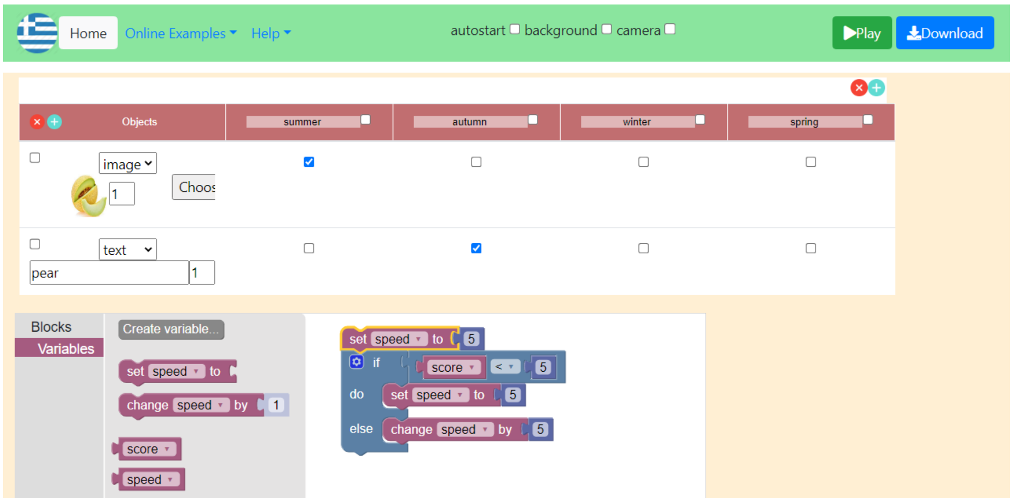

Figure 4: The SorBET block-based programming in Design Mode. The user can modify the game mechanics, like the game speed, with specialized blocks.

For the purposes of this study, we designed two SorBET games, focusing on two diverse scientific areas. The rationale for having two games was a) to be able to study the development of student classification operations in different subject content (RQ1) and b) to explore whether the use of classification operations by students allows meaning-generation and knowledge development in different subjects (RQ2). Both games are designed to bring into the foreground the notions of union, intersection, difference, and exclusivity of data categories based on the recognition and analysis of objects' and categories' common or unique properties. These are core operations of both classification and data science which however have not been given the necessary attention as research objects of educational studies.

The first, called "Falling Angles", is a math game focusing on the concept of angle. The game approaches the notion of angle through different representations drawn from real-life objects in contrast to the traditional abstract representation in school textbooks. In this game, the player has to classify falling pictures or text representing objects in an angle, e.g., clock hands, bird wings, time, hands position, to five angle categories (acute, right, obtuse, straight, non-reflex). Some pictures can be categorized in more than one category since they depict more than one angle.

Figure 5: The "Falling Angles" game. The player classifies pictures according to the angles they depict.

The second, called “App Classifier”, is a game focusing on the categorization of popular mobile applications, such as YouTube, Twitter, and Instagram, into categories describing the purpose of use. The player categorizes the fallen App icons into 5 categories, i.e., communication, photo/video editing, dating, fun, and self-promotion. The applications are intentionally chosen so that their purpose of the use is not clear, aiming to raise discussions between players about the best-fit category based on their personal experience.

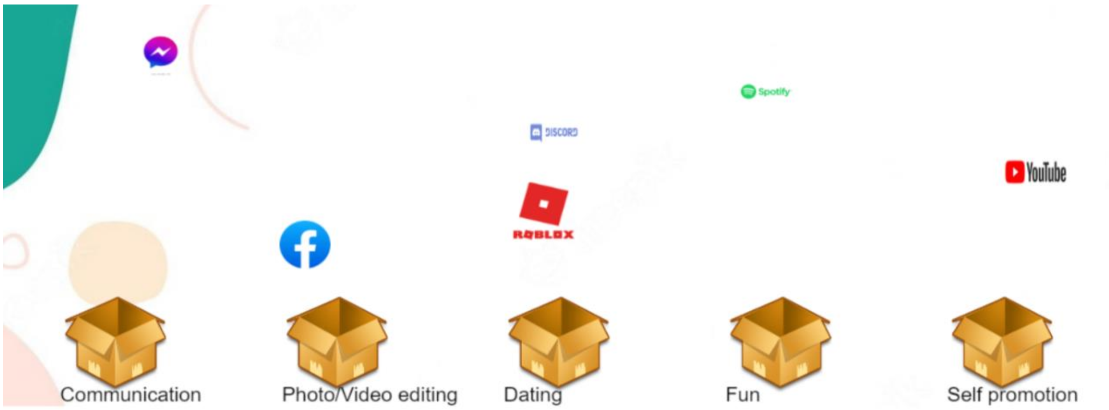

Figure 6: The App Classifier game. The player classifies popular applications according to their usage.

Methodology

Context and Participants

This study is the pilot part of a larger ongoing design-based research (Barab & Squire, 2004) exploring the development of student 21st-century skills, including computational thinking, with constructionist digital media and emerging technologies.

The study was organized in a middle school in the region of Athens, Greece, with the participation of a researcher and a math teacher. The participants were six students, four boys and two girls, aged 13-14 years old who participated voluntarily. The duration of the intervention was 4 hours split into two 2-hour sessions with one week difference. All students were informed about the study context, purpose, data collection and analysis processes with a written announcement and they voluntarily expressed participation interest. All participants and their parents gave written consent.

Activities

The participants worked in 3 groups of 2 students each that were formed randomly by the math teacher. Each group used a school computer for playing and modifying the Falling Angles and the App Game. Each 2-hour session was divided into three parts. In the first session, each team played the Falling Angles game several times, filling in a reflection sheet with questions about their classification strategies in the game. In the second part, they modified the game creating a new version of it, without any restrictions about the changes they will make. Finally, in the third part, each group played the game of another group, giving oral feedback and comments. In the second session, the same process was repeated with the App Game.

Data collection and analysis

In qualitative studies, the collection of various data resources is necessary to form a coherent picture of the actions and interactions of participants during the learning experience (Bakker, 2018). Thus, in this study, the researchers collected five types of data resources: screen and audio recordings of each group captured through their computer with HyperCam 2.0. software, student worksheets, students' modified games, researcher observation notes, and interviews with each group at the end of each session. The interviews were semi-structured and included questions about a) the strategies they developed while playing the game, b) the justification of the design choices they made while modifying the game and c) the evaluation of the games and the SorBET environment.

To develop a deep understanding of how students developed strategies throughout the activity the researchers performed a qualitative thematic analysis of the collected dataset in three stages. First, they transcribed the audio recordings and the interviews using anonymization techniques. The transcriptions were then correlated with screenshots to provide a complete picture of student activity. Then two researchers analyzed and coded the transcribed using the "critical incident" as the analysis unit. A critical incident is a representative moment of student activity relevant to the research questions of the study (Tripp, 2011). For coding the incidents, the researchers employed the abductive coding technique (Tavory & Timmermans, 2019), that is to start the analysis with an initial coding scheme which is then modified and enhanced with new emergent codes leading to a final scheme and themes after several iterations of coding comparisons, clustering, and merging. This approach allowed them to remain open to emergent findings. For creating the initial coding scheme, the researchers combined a) selected CT practices from the CT-MS Framework (Weintrop et. al., 2015), b) selected Focal Knowledge, Skills and Abilities (FKSAs) for Data Analysis learning (Basu et. al., 2021) and c) the information literacy abilities as described in competence 1.1. of the DigComp2.2 EU Framework (Vuorikari et. al., 2022), resulting to a first set of 25 codes. The selected elements of each Framework are included in Appendix 1 (some of them were merged to create the coding scheme). At the end of the first coding cycle, they triangulated the coded critical incidents with student worksheets and modified games to enhance their validity. The data analysis was done in NVIVO software in 2 cycles resulting in 126 critical incidents coded with 34 original codes.

Results

Emergent themes

The qualitative thematic analysis resulted in four themes, each including a set of codes and subcodes. Theme 1 refers to critical incidents (or series of incidents) in which students implemented, explained, or discussed a data practice (e.g. data collection) or a classification operation (e.g. set theory) to cope with the game data and their representations either in the game play or in the game design stage. For instance, the code "*Data collection*" refers to the ability to identify what types of data and information should be collected based on a certain purpose and to identify and collect these data or information from several resources in digital environments successfully and efficiently (Basu et. al., 2020; Vuorikari et. al., 2022). The "*Set Theory→Intersection*" code and subcode (→) refer to the process of identifying or creating intersections between the game categories and recognizing objects belonging to more than one category. Theme 2 includes incidents in which students implemented or discussed a Computational Thinking practice or concept, other than data practices, for dealing with game play or game design. For instance, the "concept of class" code refers to incidents where students generalized the falling object characteristics referring to a more abstract entity with common properties, i.e., a class. Theme 3 includes incidents related to students' critical engagement with the game content and structure such as the expression of disagreement on the classification scheme or the game categories. Finally, the fourth theme, which is strongly connected to the three others, refers to incidents where student interaction with each other, either within the group or between groups, affected the development of data practices, CT practices, or critical engagement with the game. For example, an incident of disagreement between students on whether an object belongs to one category or another led to meaning generation on the concept of angle for supporting their opinion. In the following sections, we present the results for the two research questions, deepening into some of the codes with examples of relevant critical incidents.

Table 1: Emerged themes and codes from the bottom-up thematic analysis

Theme	Examples of codes and subcodes (→)	Related Research Question (s)
1) **Data practices & classification operations** (FKSAs, DigComp 2.2., CT-MS Framework + emergent codes)	**Data collection** →efficient data search, appropriate data representation **Data interpretation & analysis** → organizing, filtering, comparing, properties discrimination, identifying correlations, defining rules to categorize. **Data model refinement/creation** → Data transformation, classification model design, creation of data relations **Data representation** → visualize for the player, different representations **Classification criteria** → formal, visual, personal, popular **Set theory** → Intersection, inclusion, exclusion (of data classes)	RQ 1
2) **Other CT practices** (CT-MS Framework + emergent codes)	**Concepts** → Concept of object, Concept of class **Practices** → Abstraction, Pattern recognition, Debugging	RQ 1

3) **Critical Computational Thinking** (DigComp 2.2. + emergent codes)	Disagreement with game content Bias recognition Bug recognition	RQ 2
4) **Social interactions** (Emergent codes)	Disagreement Feedback/Reflection Explanation	RQ 1 & 2

RQ1: Data and CT practices students developed through the classification games

Regarding the first research question, the analysis revealed that students developed and implemented strategies mostly related to data interpretation and data model refinement and to certain computational thinking practices while playing and modifying the two classification games. Below we have selected to discuss three frequent strategies based on the number of relevant critical incidents.

Data interpretation & analysis for classifying the objects in gameplay

Since students did not receive any instructions beforehand, they had to discover the classification model themselves through experimentation. This led them to develop strategies in order to identify what exactly they had to categorize and based on which properties. One frequent strategy concerned the analysis of the falling object's properties and their comparison to the categories' properties to recognize similarities and patterns and to come up with *criteria for classification*. This strategy was coded as "*data interpretation & analysis*" and the relevant incidents were further coded with the subcodes that better fit the situation (Table 1). It relates to the ability to interpret, manipulate and analyze data models and visualizations with computational tools for making predictions, making claims or drawing conclusions (Basu et. al., 2021, Weintrop & Wilensky, 2015). It also involves the ability to organize and store data and information in a structured way, as it is described in the latest Digital Competencies Framework of the EU (Vuorikari et. al., 2022).

We identified 3 types of classification criteria that students developed in order to organize the data into classes: a) *formal*, which is based on formal definitions or rules, e.g., the formal definition of angle or the original purpose of the app, b) *visual*, which is based on the representation it appeared on the screen, e.g., how the angle is represented in the picture, and c) *personal*, which is based on personal views or opinions that are beyond formal definitions or visual representations. One example of all three criteria is shown in the interview transcript in table 2.

Table 2: Interview transcript – group 2 students use different classification criteria

Transcript	Code
Researcher: How did you choose where to categorize the falling objects?	
S2: At first, we looked for the most obvious angle and classified it according to whether it was less than equal to or greater than 90 degrees or 180 degrees…	*Formal criterion*
… but then, in pictures like the eagle or the chair we searched for all possible angles it depicted	*Visual criterion*

S3: Sometimes we tried to imagine the animal from another point of view, and not only from the camera's, to find all the angles it can contain.	*Personal criterion*

The interview transcript also shows a progression in their criteria strategy that was detected in the two other groups as well. All groups started by playing the game with formal criteria but as their engagement progressed, they focused on visual criteria making the classification model more complex. Personal criteria were more frequent in the app game, which involved more subjective categories than in the math game. For instance, for the second game, two groups discussed whether they should categorize the falling application based on their original design, their personal usage or the most popular usage. On the contrary, visual criteria were more frequent in the math game, in which the visual representation could be logically connected to the game categories (e.g. angles).

For the App game, the classification criteria were coded as shown in critical incident 1 (table 3). In this case, there was no visual criterion, but rather the popular app usage, according to both their opinion and facts they searched on the internet. The formal criterion was related to the original design purpose of the app based on its technical characteristics or terms of use. The personal criterion was relevant to the student's personal usage of the App. Since this game had a bigger level of subjectiveness than the math game, students developed different interpretations of the game data. For instance, in critical incident 1, students of group 3 discuss how they should modify the game to make it more “right” according to their views, switching between the three classification criteria.

Table 3: Critical Incident 1 - Group 3 students discuss different uses of the Spotify Application

Transcript	Codes
S6: I think that all objects can fit into all categories	
S5: Well, is not that common to use Spotify for dating	*Popular Use*
S6: Yes, but one may do it. Is not forbidden	*Disagreement*
S5: We have to think about how we will design it. Based on what most people do or what we do?	*Personal Criterion*
S6: Or what it was created for? Because for instance the terms of use of Roblox forbid dating but many people do it	*Formal Criterion* *Popular Use*

Game data model refinement & design in classification game modding

This strategy refers to the ability of students to refine, create and use the data to design an appropriate model that addresses a certain question and demonstrates relationships within the data (Basu et. al., 2021, Weintrop & Wilensky, 2015). The majority of relevant critical incidents were detected during the modding phase of both games, that is when students edited the games in design mode using the interactive database and block-based programming. These involved cases where students either redesigned the dataset and rules of the original game, e.g., by adding more data (game objects) or more categories (game classes), changing the game speed based on the player’s score, or designing a new data model from scratch for a different topic. For instance, group 3 designed a new database so that the player classifies pictures of objects, shapes or letters (e.g. Greek letter Δ) into five geometrical shapes classes, i.e., right triangle, regular polygon, equilateral triangle, right rectangle and oblique parallelogram (Figure 7).

During game design the students discussed and developed understanding about the appropriate data that should be included in their game, their quantity and representations, e.g. photos of real-life objects, text, formal mathematical shapes, and the relations between the game categories, e.g. exclusivity, inclusion of some categories, categories types.

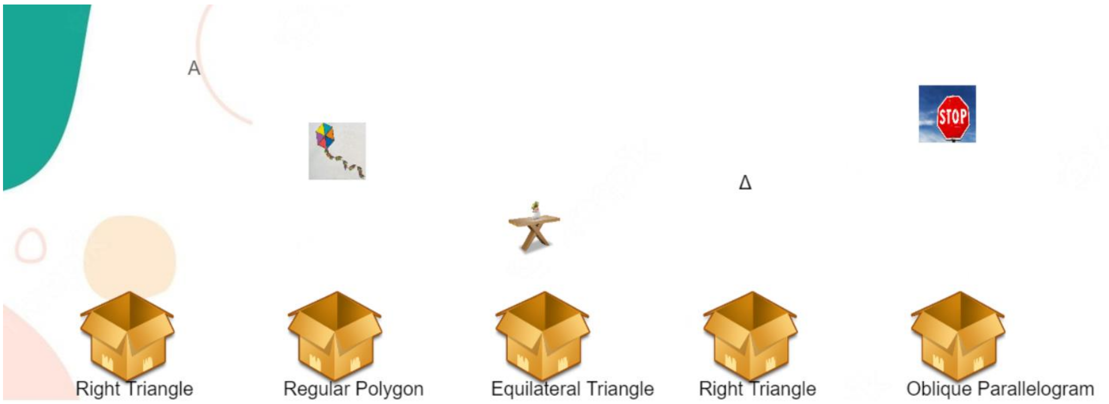

Figure 7: Screenshot from group 3 students testing their game.

In critical incident 2 (Table 4), group 3 students are editing their game after some first trials, having decided to include some photos from real-life objects since "*the game would be more fun and cleverer*". The students search Google images for the appropriate image to represent a pentagon to the player. The images of kites drew their attention as they included more than one shape (line 4) and they could be interesting for their game data model (Figure 8). Then they start discussing how such an image could fit their model and whether it would belong to more than one category. In the end, S5 based on the kite image properties, which they both have agreed is a good data choice, suggests creating a new category in their classification model that would include other categories as well.

Table 4: Critical Incident 2. Group 3 students design the data model of their game in the Design Mode

Transcript	Codes
S5: We should think something from real-life that is a pentagon	*Data collection* *Data representation*
S6: [after some pause] what about a kite?	
[They search in google images]	
S5: It's not a pentagon, but it is a good choice since it has many shapes in it	
S5: And it would fit into more than one categories	*Data model creation →* *Classification model design* *Set Theory → intersection*
S6: Yes! We can put that one that shows both a polygon and a triangle	*Data model creation →* *Classification model design* *Set Theory → intersection*
S5: And this is a trapezoid with right triangles	
S6: But we haven't trapezoid in the game categories	*Classification model design*
S5: hmm, maybe we can create a category quadrilateral that will include all rectangles but also squares, trapezoids and any shape with four sides	*Creation of data relations,* *Set Theory → inclusion*

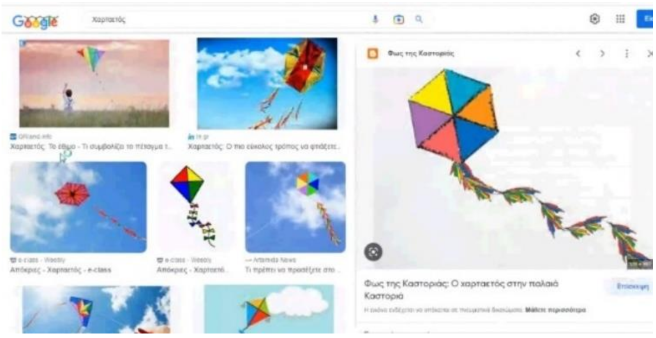

Figure 8: Group 3 students collecting data for their game.

Pattern Recognition and Abstraction practices

Students also developed certain Computational Thinking practices, with the most frequent being pattern recognition and abstraction. Pattern recognition was developed in the forms of either recognizing patterns amongst the falling objects, e.g "*all birds will have an acute or an obtuse angle in their wings*" (group 2), or following patterns in their gameplay or design strategy, e.g., "*let's put 3 objects for each category to have a game balance*" (group 1, design mode). Abstraction was expressed through the concepts of classes and objects. For instance, group 2 discussed several times the idea that the falling images are specific instances (objects) of one category (class), e.g. "*The owl image has a similar wingspan to the eagle one, so it goes to the acute angle category*". In critical incident 3 (table 5) group 1 students, after having played the game several times, abstract the patterns they had recognized to a general rule that could be applied to any picture. This is also a general math rule that they are not taught in school, but they discovered (as they also claim) through their experimentation with and modification of the classification game.

Table 5: Critical Incident 3 – Group 1 students express an abstract rule for the non-reflex angle

Transcript	Codes
S2: So, all angles have a reflex angle from the other side	*CT practices → Pattern Recognition*
S1: Not all. The straight angle, 180 degrees, doesn't	*CT practices → Pattern Recognition*
S2: Yes, you are right.	
S1: All objects that have one acute or one obtuse angle also have a non-reflex one	*CT practices → Abstraction*
S2: Sir! We discovered a new rule!	*CT practices → Abstraction*

RQ2: Critical Engagement with Computational Thinking through game modding

The subjective nature, especially of the second game, combined with the feature of modding provided by the tool, urged students to doubt its content and develop a critical perspective towards its design. A large number of relevant critical incidents (39 out of 126 in total) led us to the creation of the third theme "Classification and Critical Thinking", which was not part of the initial research questions. The theme involves strategies such as disagreeing with the game content, especially in the second game, analyzing the game's validity and identifying bugs, inconsistencies, or biases in the game content. For instance, in critical incident 4 (table 6) group 1 students doubt the validity of the App game because the categorization model does not agree with their personal views on the topic. This brings to the foreground different views on how the App is used, but also possible biases students or the game designer may have (line 5).

Table 6: Critical Incident 4 - Group 1 students doubting the validity of the App game.

Transcript	Codes
S1: Facebook for dating??	
S2: What? But who uses Facebook for dating? Are they serious?	*Disagreement with game content*
S1: And it doesn't belong in any other category!	*Inconsistency*
S2: Sir! This game is wrong!	*Disagreement with game content*
S1: Or whoever made it doesn't know how the Apps are being used these days (they laugh)	*Disagreement with game content, Bias*
[open the design mode before finishing the game and start modifying it - Figure 8]	
Teacher: Are you modifying it already?	
S1: Yes sir. Because some objects belong to more than one category and some others where wrong	*Critical engagement*

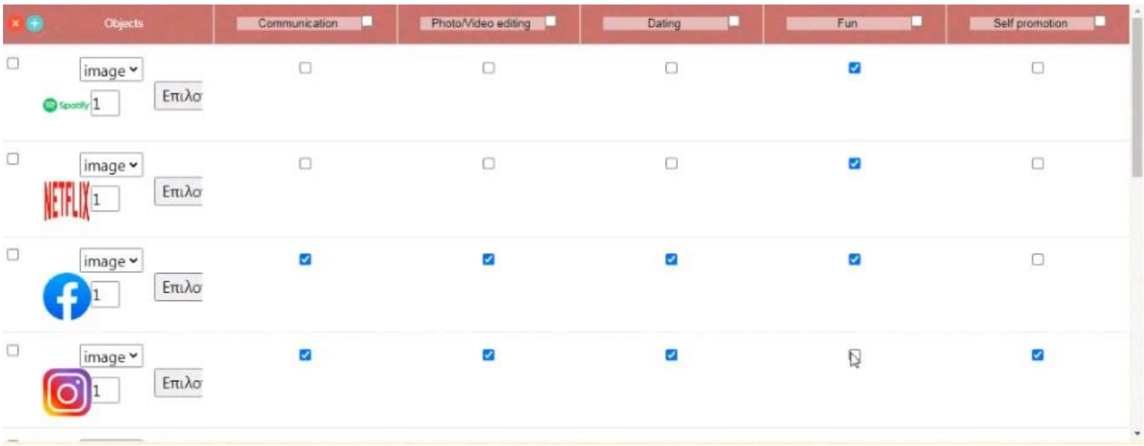

Figure 9: Group 1 students modify the App game database in Design Mode

Another interesting example with many relevant codes in the analysis comes from group 2, who modified the App game to create a geography game about different cultures across continents. Their game consisted of 5 classes, i.e. Europe, Asia, Africa, America, and Oceania and the falling objects were photos or text of cultural objects such as food, music instruments, monuments, speaking languages (Figure 10). During the game design, students expressed their personal knowledge, mainstream ideas and probably biases, about different civilizations. For instance, S3 claimed that "They must speak English in all continents since it is a universal language". This led several times to disagreements on the correctness of the data model which in turn resulted to cross-checking their claims with official sources on the internet. Yet, for some cases, they found contradicting results which led them to think more critically about the structure of the data model.

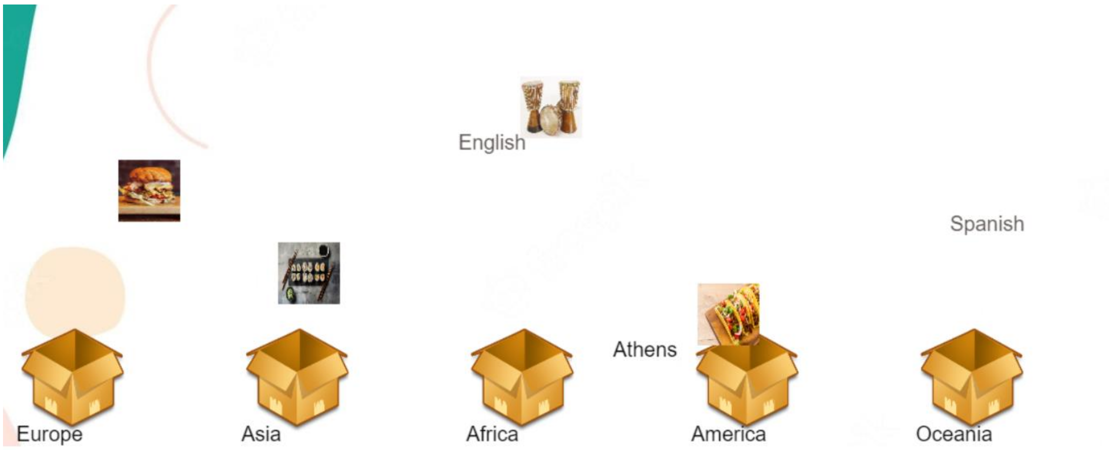

Figure 10: Screenshot of group 2 modified game

In general, the possibility of easily modifying an existing game motivated students to look at the game through a critical lens and express their disagreements with its design. Even in the math game, which is more objective, group 1 expressed doubts about its original design and modify it to make it "*more fun and mathematically correct*" according to their interview. This critical perspective relates directly to the ability to analyze, compare and critically evaluate the credibility and reliability of sources of data, information and digital content, as described by skill 1.2 of the recent DigComp 2.2 Framework (Vuorikari et. al., 2022).

Discussion and Conclusion

The presented study explored data and computational thinking practices that middle school students develop when they collaboratively play and modify digital classification games. The open analysis of participant dialogues throughout the implementation allowed the researchers to identify student practices based on existing relevant literature but also to remain open to new unexpected behaviours, patterns and strategies that may emerge. In this section we discuss the study results in two axes, aiming to respond to the initial research questions.

The first axis concerns the value of the classification process in approaching and studying student data science practices through a computational thinking lens, as Weintrop et. al. (2015) do in their CT-MS framework. Supporting students working with data and developing data practices seems to involve several aspects that may differ from cases of professionals' or adults' activity with data. An important aspect found also in the study of Basu et. al. (2021) was that students develop different criteria for the selection, analysis and manipulation of data. In their study, some students used the criterion of an artist/song popularity while others their personal preferences or their understanding of popular culture to make in-game decisions. A similar result occurred from our study as well, as we identified and coded 4 types of criteria in which students classified the game data, i.e. fallen objects: personal, formal, visual and popular usage (Tables 2 & 3). Even in the math game, in which the data are objective and based on certain math rules, students used different criteria for classifying and organizing the game objects (Table 2). This is something that needs to be taken into account when designing and evaluating data activities for students and may be interesting to further investigate it.

A second aspect is students' ability to intervene with the data model. In contrast to Basu et.al. study (2021), in which most students chose not to explicitly change the game dataset and rules, in our study students, got gradually more and more engaged with changing the game data model and even creating a new one, like the group 3 example. The process of classification game design seems to have enabled students to apply classification operations such as set theory and properties discrimination to efficiently collect data and (re)design the dataset of their game. Moreover, it seems that the type of classification model (one to many) urged discussions about the concepts of objects and classes, e.g. whether a fallen object is an instance of one category and its similarities or differences with other objects belonging to the same category. This result thus indicates that classification in open-ended constructionist environments can be a valuable process and contribute to otherwise difficult practices for young and inexperienced students, like data design.

The second axis concerns the value of game modding and questioning in developing computational thinking skills through a critical perspective. Giving students computational access to the game structure, raised discussions about the game's validity and put them in the roles of evaluator and designer rather than just the player. This led them to develop a critical interpretation of the game, especially in the second case of the application game. This shows that enabling students to question, disagree and change the classification content, could contribute to the recent efforts towards "critical computational thinking" (CCT) (Kafai, Proctor & Lui, 2020; Lee & Soep, 2018). CCT framework sees seeing computational thinking as a tool for children to engage critically with technological artefacts, e.g. games, and unveil biases or other issues behind their design. Similar to what the CCT framework describes, in this study students used the computational tools of SorBET, not only for technically developing a new game but also for criticizing and reflecting on the original game's axioms and values. This result indicates that the play and design of classification games, like the ones in SorBET, could be a strong vehicle for engaging students with subjective, doubtable issues with no clear solution, like socio-scientific issues and wicked problems. It also shows how critical computational thinking is strongly connected to information literacy ability to analyze, compare and critically evaluate the credibility and reliability of data sources and technologies (Vuorikari et. al., 2022).

The study had also some limitations that should be taken into consideration. Since this was the first version of the tool it had some technical issues that prevented students use the block-based programming feature for a long time. Thus, the added value of this affordance was not studied sufficiently, and more research is required. In addition, students had limited time for designing a new game, which prevent students from implementing more complex ideas, especially regarding falling objects. Moreover, the qualitative methodology, even though it provided in-depth information about students' learning process, the results cannot be applied to the general population without investigation and validation of the findings for a larger number of students with different backgrounds. Future studies with mixed methodology (Qual+Quant) and a larger number of participants are necessary to make the results more generalizable.

Thus, it seems that there is value in researching classification as a widely applicable and higher-order competence that could contribute to the ongoing research on the development and scientific sustenance of computational thinking and information literacy as well as the teaching and learning of STEM concepts. With more research in that direction, new theories and approaches could be developed about the cultivation of integrated information and computational literacy in education.

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References

Bakker, A., & Derry, J. (2011). Lessons from inferentialism for statistics education. Mathematical Thinking and Learning, 13, 5-26.

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *The journal of the learning sciences*, *13*(1), 1-14.

Basu, S., Disalvo, B., Rutstein, D., Xu, Y., Roschelle, J., & Holbert, N. (2020). The role of evidence centered design and participatory design in a playful assessment for computational thinking about data. In Proceedings of the *51st ACM Technical Symposium on Computer Science Education* (pp. 985-991).

Biehler, R., Ben-Zvi, D., Bakker, A., Makar, K. (2012). Technology for Enhancing Statistical Reasoning at the School Level. In: Clements, M., Bishop, A., Keitel, C., Kilpatrick, J., Leung, F. (eds) Third International Handbook of Mathematics Education. Springer International Handbooks of Education, vol 27. Springer, New York, NY. https://doi.org/10.1007/978-1-4614-4684-2_21

Cao, Y., Kurbanova, A. T., & Salikhova, N. R. (2017). Development of classification thinking in future teachers: Technologies of reflective discussion. *EURASIA Journal of Mathematics, Science and Technology Education*, *13*(6), 1865-1879.

Denner, J., Werner, L., & Ortiz, E. (2012). Computer games created by middle school girls: Can they be used to measure understanding of computer science concepts? *Computers & Education*, 58(1), 240–249.

diSessa, A. (2001). *Changing minds: Computers, learning and literacy*. Cambridge, MA: MIT Press.

Dolgopolovas, V., Dagienė, V., Jasutė, E., & Jevsikova, T. (2019). Design science research for computational thinking in constructionist education: a pragmatist perspective. *Problemos*, 95, 144-159.

El-Nasr M.S, & Brian S. K. (2006). Learning through Game Modding. *Computers in Entertainment* (CIE) 4(1), 7

Fessakis, G., Komis, V., Mavroudi, E., & Prantsoudi, S. (2018). Exploring the scope and the conceptualization of computational thinking at the K-12 classroom level curriculum. In *Computational Thinking in the STEM Disciplines* (pp. 181-212). Springer, Cham.

Gee, J. P. *What Video Games Have to Teach Us about Learning and Literacy*. 1st ed. New York: Palgrave Macmillan. (2003).

Giama E. (2020). A web application for the design of student activity supporting the understanding of classification. [Master's Thesis Dissertation, National & Kapodistrian University of Athens]. Pergamos Repository

Grizioti, M., & Kynigos, C. (2021). Code the mime: A 3D programmable charades game for computational thinking in MaLT2. *British Journal of Educational Technology*, *52*(3), 1004-1023.

Grover, S., & Pea, R. (2018). Computational thinking: A competency whose time has come. In *Computer Science Education: Perspectives on Teaching and Learning in School*, (pp. 19–37). London: Bloomsbury Academic.

Holbert, N., & Xu, C. (2021). Make with Data: Challenging and contextualizing open-source data with personal and local knowledge. In *Proceedings of the 15th International Conference of the Learning Sciences-ICLS 2021*. International Society of the Learning Sciences.

Jacob, S. R., & Warschauer, M. (2018). Computational thinking and literacy. *Journal of Computer Science Integration*, 1(1).

Kafai, Y. B., & Burke, Q. (2016). *Connected gaming: What making video games can teach us about learning and literacy*. Mit Press.

Kafai, Y., Proctor, C., & Lui, D. (2020). From theory bias to theory dialogue: embracing cognitive, situated, and critical framings of computational thinking in K-12 CS education. *ACM Inroads*, *11*(1), 44-53.

Karadimitriou K., & Roussou M. (2011). Studying Player Experience in a Collaborative Embodied Interaction Game. In *Third International Conference on Games and Virtual Worlds for Serious Applications*, Athens, Greece, 2011, pp. 199-206, doi: 10.1109/VS-GAMES.2011.51.

Kite, V., Park, S., & Wiebe, E. (2021). The Code-Centric Nature of Computational Thinking Education: A Review of Trends and Issues in Computational Thinking Education Research. SAGE Open, 17.

Krnel, D., Glažar, S. S., & Watson, R. (2003). The development of the concept of "matter": A cross-age study of how children classify materials. *Science Education*, *87*(5), 621-639.

Kynigos, C. (2015) Constructionism: Theory of Learning or Theory of Design? In *Selected Regular Lectures from the 12th International Congress on Mathematical Education*. Sung Je Cho (Ed.), © Springer International Publishing: Cham, Heidelberg, New York, Dordrecht, London, Switzerland, 417- 438. DOI 10.1007/978-3-319-17187-6

Kynigos, C. (2008). Black-and-white-box perspectives to distributed control and constructionism in learning with robotics. In *Proceedings of SIMPAR workshops* (pp. 1-9).

Kynigos, C., & Grizioti, M. (2020). Modifying games with ChoiCo: Integrated affordances and engineered bugs for computational thinking. *British Journal of Educational Technology (BJET) 51 (6). pp. 2252-2267. doi:10.1111/bjet.1289*

Kynigos, C., & Yiannoutsou, N. (2018). Children challenging the design of half-baked games: Expressing values through the process of game modding. *International Journal of Child-Computer Interaction*, *17*, 16-27.

Kynigos, C., Grizioti, M. (2018) Programming Approaches to Computational Thinking: Integrating Turtle Geometry, Dynamic Manipulation and 3D Space. *Informatics in Education,* 17(2), Vilnius University, 321-340.

Kynigos, Smyrnaiou & Roussou (2010). Exploring rules and underlying concepts while engaged with collaborative full-body games in *Proceedings of the 9th International Conference on Interaction Design and Children*. ACM.

Lee, C., & Soep, E. (2018). *Beyond coding: Using critical computational literacy to transform tech*. Texas Education Review.

Mannila, L., Dagiene, V., Demo, B., Grgurina, N., Mirolo, C., Rolandsson, L., & Settle, A. (2014). Computational Thinking in K-9 Education. *Proceedings of the Working Group Reports of the 2014 on Innovation & Technology in Computer Science Education Conference* - ITiCSE-WGR '14, 1–29. https://doi.org/10.1145/2713609.2713610

Micklo, S. J. (1995). Developing young children's classification and logical thinking skills. *Childhood education*, *72*(1), 24-28.

Mike, K., Ragonis, N., Rosenberg-Kima, R. B., & Hazzan, O. (2022). Computational thinking in the era of data science. *Communications of the ACM*, *65*(8), 33-35.

Milne, C. (2007). Taxonomy development: assessing the merits of contextual classification. *Records Management Journal*

Nikolaou MS (2022). Design and development of a digital kinesthetic game to support embodied learning of classification skills. [Master's Thesis Dissertation, University of West Attica]. Polynoe Repository https://polynoe.lib.uniwa.gr/xmlui/handle/11400/2899

Örnekoğlu Selçuk, M., Emmanouil, M., Grizioti, M., & Van Langenhove, L. (2021). Game modding for learning design thinking on an e-learning platform. In *7th International Conference on Designs for Learning* (pp. 84-85).

Owen, K., & Barnes, C. (2019). The development of categorization in early childhood: a review. *Early Child Development and Care*, 1-8.

Paparistodemou, E., & Meletiou-Mavrotheris, M. (2008). Enhancing reasoning about statistical inference in 8 year-old students. *Statistics Education Research Journal*, *7*(2), 83-106.

Papert, S. (1980). Mindstorms: Children, computers, and powerful ideas. Basic Books, Inc.

Rubin, A. & Hammerman, J.K.L. (2006) Understanding data through new software representations, in Thinking and Reasoning with Data and Chance—2006 NCTM Yearbook, National Council of Teachers of Mathematics, Editors: Gail Burrill

Sotamaa, O. (2010). When the game is not enough: Motivations and practices among computer game modding culture. *Games and Culture*, 5(*3*), 239–255.

Tavory, I., & Timmermans, S. (2019). Abductive analysis and grounded theory. *The SAGE handbook of current developments in grounded theory*, 532-546.

Tikva, C., & Tambouris, E. (2021). Mapping computational thinking through programming in K-12 education: A conceptual model based on a systematic literature Review. *Computers & Education*, *162*, 104083.

Tripp, D. (2011). *Critical incidents in teaching (classic edition): Developing professional judgement*. New York: Routledge.

Vuorikari, R., Kluzer, S. and Punie, Y., (2022). DigComp 2.2: The Digital Competence Framework for Citizens - With new examples of knowledge, skills and attitudes, EUR 31006 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-48883-5, doi:10.2760/490274, JRC128415.

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining Computational Thinking for Mathematics and Science Classrooms. *Journal of Science Education and Technology*, 25(1), 127–147. https://doi.org/10.1007/s10956-015-9581-5

Wing, J. M. (2006). Computational thinking. Communications of the ACM, 49(3), 33-35.

Appendix 1

Appendix 1 presents the codes from the 3 Frameworks we included in the initial coding scheme for the data analysis. Some of the following codes were merged for the coding scheme due to their similarities

FKSAs selected abilities (Basu et. al., 2021)

DCS1. Ability to identify variables or types of data that should be collected based on the purpose of the data collection.

DCS3. Ability to identify an appropriate representation for the data that is to be collected and stored given the purpose of the data and the storage constraints (includes identifying types of metadata that might be collected).

DVTI2. Ability to identify which data should be used to address a certain question.

DVTI3. Ability to transform data to highlight a specific relationship.

DVTI4. Ability to use the data to create an appropriate model that demonstrates relationships within the data.

DVTI5. Ability to interpret data models and visualizations for making predictions or drawing conclusions.

DVTI6. Ability to refine a data model using new or additional data (includes the knowledge to go back to the model to see if it still fits with new data)

CT-MS Framework selected practices (Weintrop et. al. 2015)

Data Practices → Collecting Data, Creating Data, Manipulating Data → , Analyzing Data →

Computational Problem-Solving Practices → Computational Abstractions, Debugging

DigComp 2.2 selected abilities (Vuorikari et. al., 2022)

1.1 Browsing, searching and filtering data, information and digital content.

1.2 Evaluating data, information and digital content.

1.3 Managing data, information and digital content.