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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.

Keywords: computational thinking, data science, computer science education, secondary education, empirical study, game-based learning, constructionism, educational technology

1. 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 and 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

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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 and 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 and 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 and Burke, 2016, Kynigos and 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 and Derry, 2011; Fathom, Biehler, *et al.*, 2012, Paparistodemou *et al.*, 2008, Rubin and 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 CT 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 and 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 and Piaget, 1964; Adey and Shayer, 1994). 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 CT and data science (Milne, 2007).

So, we asked ourselves, can the understanding of and engagement with classification play 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 SorBET (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 for different contexts. 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 by using high-level computational tools. To gain insight into the CT 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) Whether and which Data Practices students apply and develop in the context of CT while they are engaged with classification process through game play and design?
b) Whether and how students are critically engaged with data and CT through the process modifying the data model and rules of a classification game?

2. Theoretical Framework

2.1. *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 and Pea, 2018). Despite the extended theoretical elaborations on CT 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 and Tampouris, 2021; Tang *et al.* 2020). In practice, current CT research and approaches tend to approach CT 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 CT 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 CT 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 CT skills, like abstraction and pattern recognition, and vice versa, working with real-life data can reveal the potential of CT for dealing with important real-world problems.

It seems that there is high value in connecting data science with CT. However very few CT frameworks include data-related practices (Tikva and 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 CT. 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 and Xu (2021), have started to explore data-oriented approaches in the context of CT 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.

2.2. *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, and Watson, 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 and 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.

2.3. *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 CT is for students to design and program digital games (Kafai and 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 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 CT, system analysis and design thinking (Grizioti and Kynigos, 2021; El Nasr and Smith, 2006; 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 and Yiannoutsou, 2018; Grizioti and Kynigos, 2021). 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.

3. SorBET: A Constructionist Gaming System Integrating Data Science and CT

In order to integrate Data Science with CT in a familiar context for young learners, we developed the Constructionist Authoring System called SorBET (Sorting Based on Educational Technology) that allows the play, design, and modification of Tetris-like classification games. In Tetris, a player clicks to rotate and horizontally displace objects falling from 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 (Fig. 1). ‘Pushing’ elements can be done by picking and dragging on a screen and will be extended to also include gesture interaction. Game mechanics are designed to foster comparison, pattern recognition and abstraction of the falling objects, which are core practices of Data Science and CT. When the game is over the players can access and reflect on how they classified the objects in the game log, which they can also download as a pdf file (Fig. 2).

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 (Karadimi-

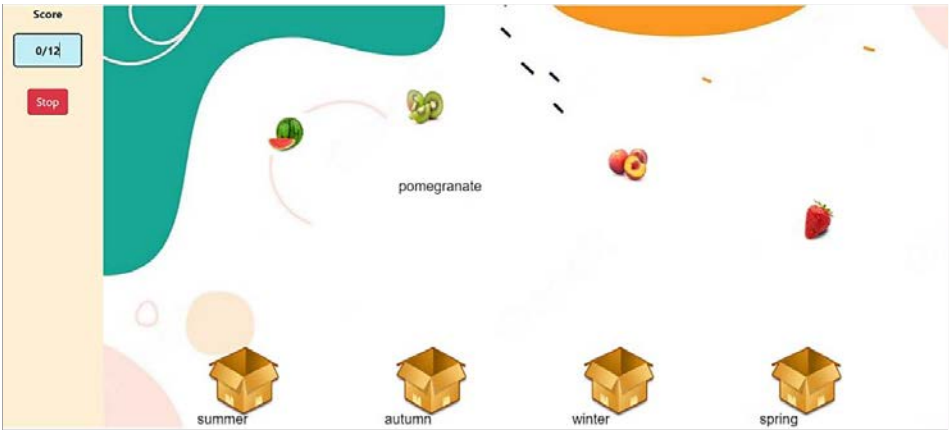

Fig. 1. Screenshot of the SorBET environment in Play Mode. Player classifies falling objects (images or text) to the category boxes.

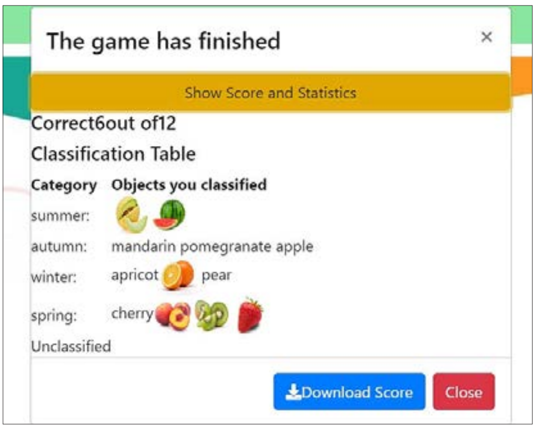

Fig. 2. The score table showing how the player classified the objects.

triou and Roussou, 2011; Kynigos, Smyrnaiou and Roussou 2010). The idea we had at our Lab was to generalize the "Sorter" game and make it authorable so that non-technical users, such as teachers and students, can design what these objects represent and what the category containers signify. The design of the SorBET system was based 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). In SorBET we expect that giving access to the game's structure with high-level computational tools, will foster a deeper understanding of the underlying concepts, such as the data model and classification rules, and, at the same time will urge critical discussions, questioning and experimentation about the game itself. Moreover, game modding would 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

Originally, we built SorBET prototypes with the help of two masters students (Nikolaou, 2022). We then proceeded to transform "Sorter" into a web-based standalone and open-source application that can seamlessly run on any device with access to the internet. We also extended its affordances with the "Design Mode", enabling the modification of the game content and rules, e.g., falling speed, density, times each object appears with two interconnected components (Kynigos, 2008), i.e., an interactive database and block-based programming. The two components were designed to make game programming, data analysis and representation accessible by users without technical expertise. The database represents the objects as rows and the categories they belong to as columns (Fig. 3 and Fig. 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 Boolean logic

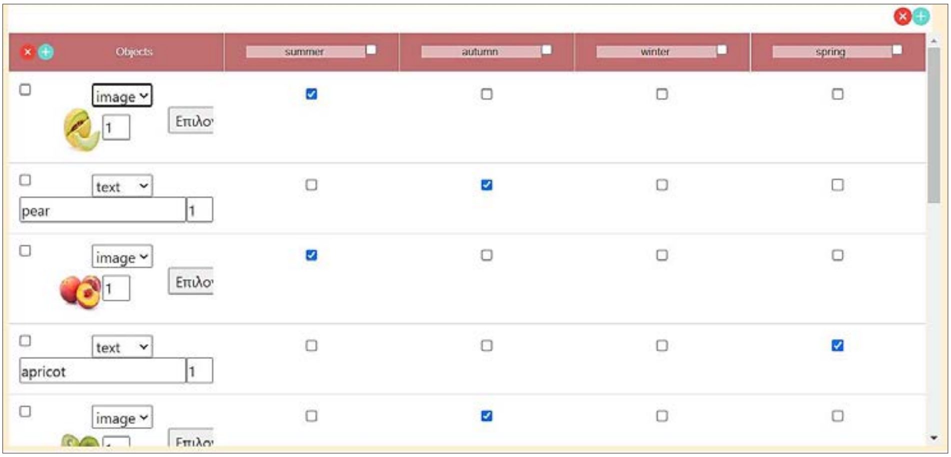

Fig. 3. The SorBET database in Design Mode. The user can modify the game categories, the falling objects, their density and the categories they belong to.

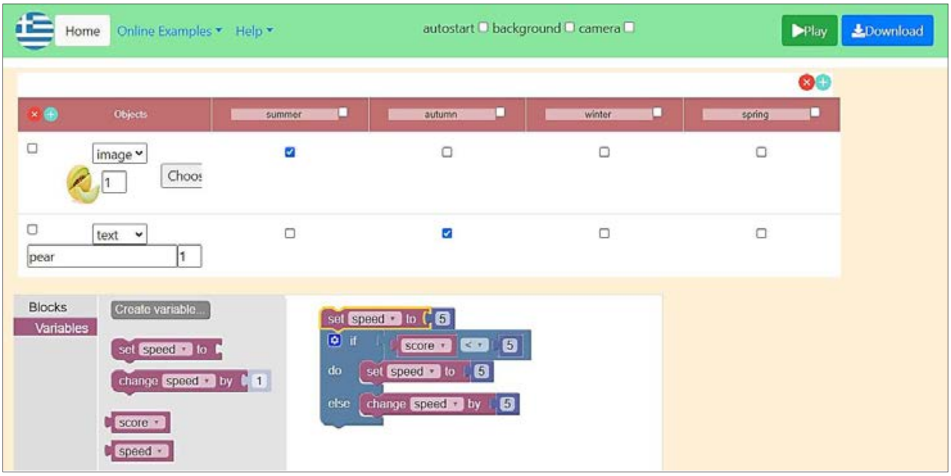

Fig. 4. The SorBET block-based programming in Design Mode. The user can modify the game mechanics, like the game speed, with specialized blocks.

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.

3.1. *Two Classification Games Developed with SorBET*

For this study, we designed two SorBET games, focusing on two diverse scientific topics. 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" (Fig. 5), 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

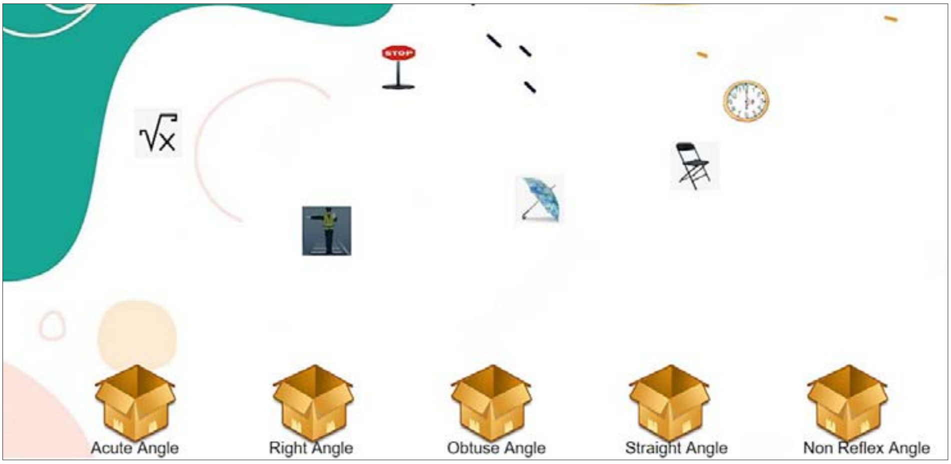

Fig. 5. The "Falling Angles" game. The player classifies pictures according to the angles they depict.

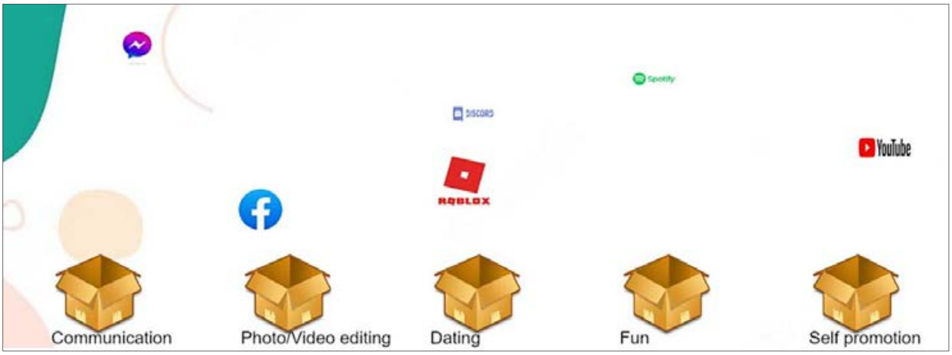

Fig. 6. The App Classifier game. The player classifies popular applications according to their usage.

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.

The second, called "App Classifier" (Fig. 6), 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 use is not clear, aiming to raise discussions between players about the best-fit category based on their personal experience.

4. Methodology

4.1. *Context and Participants*

This study sought to identify new forms of student engagement with CT that have not been studied enough before, i.e., data practices and critical CT. It was important, therefore, to analyze learners' activity and interactions between them and with the tool throughout the implementation and interpret why they happened. To achieve that in-depth analysis, a qualitative methodology was necessary (Kite *et al.* 2021). The study that is presented next is the pilot part of a larger ongoing design-based research (Barab and Squire, 2004) exploring the development of student 21st-century skills, including CT, with constructionist digital media and emerging technologies.

The study was organized in an experimental middle school in the region of Athens, Greece, with the participation of a researcher and a math teacher. It was organized as an activity of an after-school club on mathematics and STEM. The duration of the intervention was 4 hours split into two 2-hour sessions with one week difference. The participants were six students, four boys and two girls, aged 13–14 years old who participated voluntarily. According to their Computer Science teacher, they all had little experience with block-based programming, but no experience with game design or with data editing. All students were informed about the study's context, purpose, data collection and analysis processes with a written announcement and they voluntarily expressed participation interest. All participants and their parents provided written consent.

4.2. *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.

4.3. *Data Collection and Analysis*

In qualitative studies, is necessary to form a coherent and complete picture of the actions and interactions of participants throughout the learning experience and the activities (Bakker, 2018). This can be achieved by collecting and triangulating different types of data capturing participants' activity. In this study, the researchers collected five types of complementary data sources: i) screen and audio recordings of each group captured through their computer with HyperCam 2.0. software. This data source allowed the researchers to analyze student interactions between them and with the tool. The researchers analyzed students' dialogues in combination with their actions on screen to identify how they expressed knowledge and ideas on CT and data practices. Moreover, dialogues were a source of personal expression that revealed participants' perspectives, views or disagreements connected to their critical engagement with the activity. ii) student worksheets that included six open questions on student strategies while playing and modifying the two games such as "With what criterion you chose where to classify an object?" "Did you classify any objects to more than one category?". These had the role of reflection instruments that also helped researchers identify how students developed their strategies, iii) students' modified games in different stages of development to capture the process of game modding, iv) researcher observation notes regarding students' activities during the activities that could not be captured with the audio/screen recording, and v) semi-structured interviews with each group at the end of each session. The interviews 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. The researchers triangulated the resources of the data set, starting with the audio and screen capturing and using the other four resources as complementary and supporting evidence to what they identified during the analysis.

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 and correlated the transcriptions with screenshots to provide a complete picture of student activity. 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 and 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 three existing frameworks on CT and 21st century competencies that were closer to the theoretical framing of this study. The first was the CT-MS Framework (Weintrop *et al.*, 2015) that approaches CT from a math and science perspective, emphasizing data-related practices, The second was the Focal Knowledge, Skills and Abilities (FKSAs) for Data Analysis learning (Basu *et al.*, 2021) that identifies necessary competencies for data learning. The third was competence 1.1. of the DigComp2.2 EU Framework (Vuorikari *et al.*, 2022) which describes the information literacy abilities necessary for the 21st century, including critical engagement with data and data practices. The combination of practices and skills from the three frameworks resulted in a first set of 25 codes. The selected elements of each Framework are included in Appendix 1, while some of them were merged to create the coding scheme. At the end of the first coding cycle, the researchers 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.

5. Results

5.1. *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 gameplay 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 CT practice or concept, other than data practices, for dealing with gameplay 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.

5.2. *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 CT 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.

5.2.1. *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 and 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

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

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.

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, 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 the 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

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*

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*

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 the 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.

5.2.2. *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 and 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 (Fig. 7).

During game design, the students discussed and developed an understanding of 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, the inclusion of some categories, category types.

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

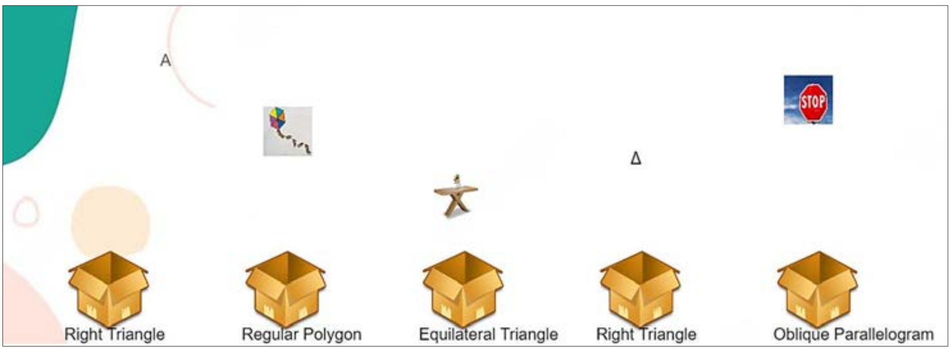

Fig. 7. Screenshot from group 3 students testing their game.

attention as they included more than one shape (line 4) and they could be interesting for their game data model (Fig. 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 category	*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*

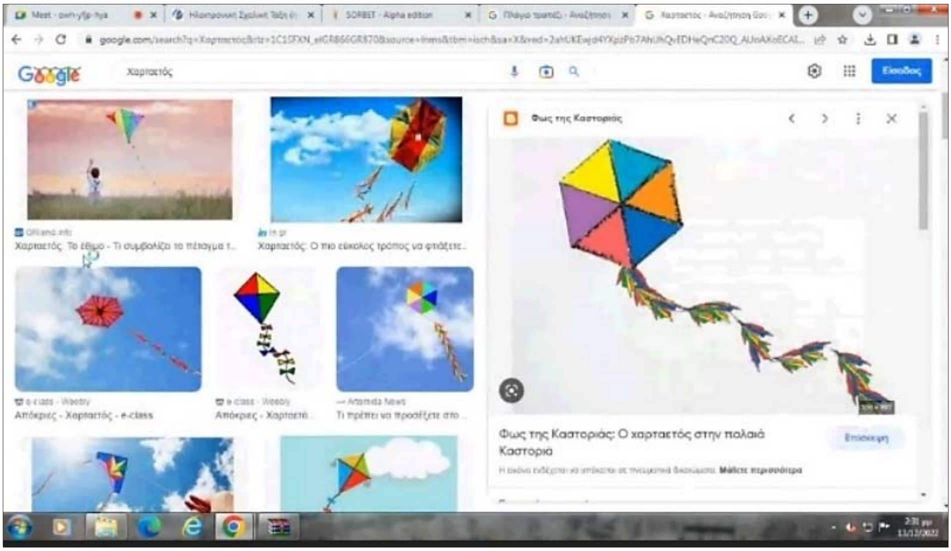

Fig. 8. Group 3 students collecting data for their game.

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*

5.2.2. *Pattern Recognition and Abstraction Practices*

Students also developed certain CT 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.

5.3. *RQ2: Critical Engagement with CT 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).

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,

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 – Fig. 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*

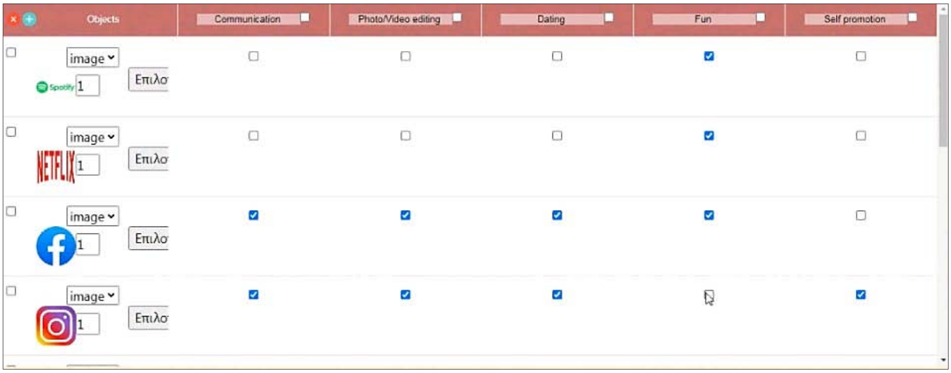

Fig. 9. Group 1 students modify the App game database in Design Mode.

and Oceania and the falling objects were photos or text of cultural objects such as food, musical instruments, monuments, and speaking languages (Fig. 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 in cross-checking their claims with official sources on the internet. Yet, in some cases, they found contradictory results which led them to think more critically about the structure of the data model.

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 modified it to make it "*more fun and mathematically correct*" according to their interview. This critical perspective relates directly to the ability to

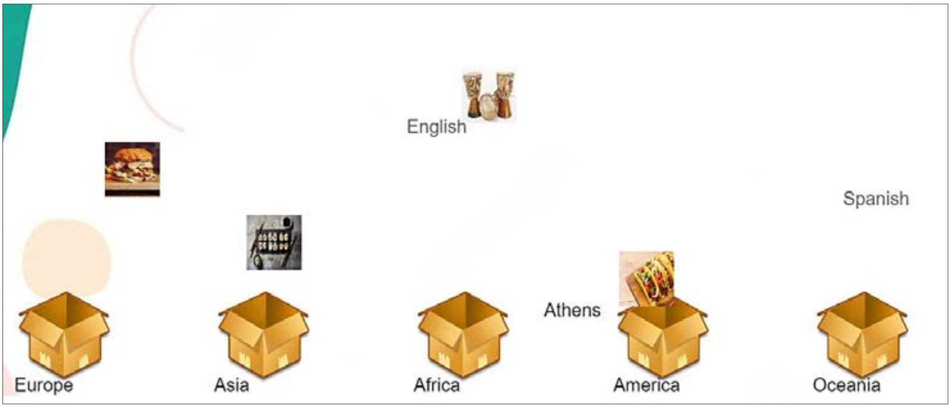

Fig. 10. Screenshot of group 2 modified game.

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).

6. Discussion and Conclusion

The presented study explored data and CT 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 unexpected new behaviors, 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 game-based classification process in enabling and fostering student data science practices through CT (2015). According to the results, while playing the two games students employed core data-related practices such as organizing and comparing the data, identifying relations between the available data (falling objects) and developing classification criteria. Moreover, the access students had to the game content through the interactive database, motivated them to further analyze and change the game data with computational means leading them to a deeper understanding of data-related concepts, such as set operations and data properties. The results also showed that the meanings and practices young learners may develop while working with data and digital information may differ from cases of professionals' or adults' activity with data. One aspect, also mentioned in the study of Basu *et al.* (2021), was that students develop different criteria for the selection, analysis, and manipulation of data in comparison to what we may expect from adults. 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. In our study, we identified and coded 4 types of criteria in which students interpreted and classified the game data, i.e., fallen objects: personal, formal, visual and popular usage (Table 2 and Table 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 finding reveals the importance of cultivating students' information and data literacy (Vuorikari *et al.*, 2022) so that they can identify and realize both subjective and objective criteria behind the design of data models, such as AI models or simulation models. It is also an aspect that needs to be considered when designing and evaluating learning activities for students that deal with data and information processing.

A second aspect is students' motivation to intervene with the data model and the processes they followed to achieve that. 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 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, according to the results, 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 finding indicates that classification in open-ended constructionist environments can be a valuable process and scaffold otherwise complex practices for young and inexperienced learners, like data editing and design.

The second axis concerns the value of game modding and questioning in developing CT 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 and Lui, 2020; Lee and Soep, 2018). CCT framework sees 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 CT 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 from using 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 prevented students from implementing more complex ideas, especially regarding falling objects. Moreover, the qualitative methodology together with the small number of participants, even though they provided in-depth information about students' learning process, also limit the applicability of the results to the general population. To make the results more generalizable, it is important to investigate and validate the findings for a larger number of students with different backgrounds, following a mixed methodology (Qual+Quant).

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 CT 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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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.