ENHANCING STUDENTS' 21ST CENTURY SKILLS THROUGH PLAYING AND MODIFYING EMBODIED DIGITAL CLASSIFICATION GAMES

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This research paper explores the pedagogical potential of playing and modifying a digital embodied classification tool to foster computational and mathematical reasoning skills as high-level 21st-century competencies. In a study involving eight secondary school students, we investigate the outcomes of utilizing a specially designed digital tool for a subjective classification. The outcomes shed some light regarding the role of such a tool in further engaging students with complex multidisciplinary concepts and collaboration development and lay the foundation for further exploration of the connection between digital embodied classifications and the development of mathematical meanings. We elaborate on a case of obtaining classification skills through digital game modding where computational and mathematical ideas coexist.

Keywords: Digital Games, Classification, Collaboration, Designing Technology, Mathematical Concepts.

INTRODUCTION

Many studies have shown the benefits of embodied interaction with technology for deeper learning and meaning generation about complex scientific concepts by students (Papert 1980; Kynigos et. al., 2010). Yet, this promising approach, has mainly been studied in silo contexts of subject knowledge development, such as maths, physics or computer science concepts understanding. In this paper, we argue that enabling embodied interactions in digital educational technologies, apart from concept understanding, can also be a strong tool for supporting children's 21st century skill development, such as classification, in a relatable and meaningful context. Classification is considered a necessary skill for dealing with society and making sense of the world with researchers including it into 21st-century skills subsets (Owen & Barnes, 2019, Vuorikari et. al., 2022). However, there are quite limited concrete examples of educational practice and tools for supporting higher-order classification processes, while most relevant studies concern basic operations with children ranging from infant to primary school age (Milne, 2007, Cao et al., 2017). To address this challenge, we explored middle school students' classification skills through their collaborative embodied interaction within a digital Tetris-like gaming environment, called "SorBET" (http://etl.ppp.uoa.gr/sorbet). "SorBET" enables students to play gesture-manipulated classification games and design their own with block-based programming and database affordances.

In this paper, we pose questions about two key factors regarding the specific digital classification tool as a medium for students' higher conceptualization. The first is about classification as a way of engaging with complex concepts in terms of computational and mathematical thinking, and the second addresses the role of embodiment in terms of student collaboration, focus and construction of higher meanings:

- How do students make sense of classification concepts while playing and modifying a classification game in SORBET?

- To what extent can the simultaneous embodied engagement of two students in a digital classification game promote collaboration and meaning-making processes?

This paper aims to showcase the potential of embodied interaction within digital educational technologies in enhancing students' classification skills and overall 21st-century skill development, while also providing concrete examples of educational practices and tools for facilitating higher-order classification processes. Before delving into these specific questions, it is important to have a deeper understanding of the concept of classification and how embodied interactivity can influence students' thinking and meaning-making processes.

THEORETICAL FRAMEWORK

Classification as a Pillar of 21st Century Skills Development

The goal of classification is to break large subjects down into smaller, and more specific components. In our daily lives, we classify things frequently, often without even realising it, which can help us understand the world around us (Owen & Barnes, 2019). This stems from the fact that applying already known patterns and categorising objects allows us to respond quickly to new stimuli (Micklo, 1995; Krnel et al., 2003). According to Piaget, successful classification requires moving from concrete operations to formal operational thinking (Inhelder & Piaget, 1964 as cited in Krnel, Glažar & Watson, 2003) and it involves higher-order mental practices as mathematical reasoning, abstraction, generalisation and design of the classification system (Grizioti & Kynigos, 2023). Classification practices are also closely connected to set theory, as they can be seen as a process of partitioning or classifying data into different sets based on certain criteria .Besides, at its core, classification relies on the principles of logic and inference, which are fundamental components of mathematical reasoning.

Nevertheless, the majority of relevant studies on the development of such skills mainly concern children from infancy to primary school ages (Micklo, 1995; Krnel et al., 2003; Owen & Barnes, 2019). These skills can be difficult for students to adopt, particularly those involved in high-order classification processes like creating classes and patterns, abstracting rules, and implementing relations within the classification system (Armoni, 2013). Classification skills are essential for deeper understanding and are linked to computational thinking, but they are often left out of school education due to their abstract nature (Cao et al., 2017).

It should also be noted that classification and categorization, while both are methods of organizing information, possess semantic differences in structure and meaning. (Jacob, 2004), Classification is rigid, requiring entities to belong to specific categories, whereas categorization is more flexible, based on recognizing similarities among entities (Jacob, 2004). Combining these two methods can assist individuals develop predictive and knowledge production abilities (Owen and Barnes, 2019). In this context, the digital tool used in this research, incorporates both the structure of classification and categorization (Grizioti & Kynigos, in press), allowing an object to be assigned to just one, several or all of the available categories without restriction.

The Role of Embodied Interactions in Learning

In order to enhance students' 21st century skills, using immersive digital technologies that utilize physical interaction to help them comprehend complicated ideas and generate scientific meanings, can be an effective educational strategy (Weisberg & Newcombe, 2017). As these digital tools have an impact on the education sector, it's important to consider how students engage with them. When playing a digital educational game, most of the time students have a passive role by simply using the mouse and keyboard. Such actions may have a negative effect on them, spending a great amount of time staring at the computer screen. According to Shapi'i & Ghulam (2016), a good learning experience ought to involve all the senses and activate the extremities by making them react to stimuli. This is followed by the Natural User Interface (NUI), giving a new way of learner-computer interaction. NUI refers to sensory inputs such as touch, speech and gestures (Shapi'i & Ghulam, 2016), freeing users from peripheral computer devices, enabling an intuitive and virtual experience with digital content (Johnson-Glenberg et al., 2014). This interaction has its basis in the theory of embodied cognition.

When we refer to embodied cognition, we are discussing experiences and actions that involve either the whole body or the use of just the hands manipulating objects (Fyhn, 2007; Johnson-Glenberg et al., 2014). The theory of embodied cognition, or embodied learning, is studied by cognitive and social psychology as well as by neuroscience and linguistics, and argues that human knowledge is not isolated as a perceptual action, but is closely linked to the activities of the body which is the "mediator" between the mind and the environment (Barsalou, 2010; Shapiro 2011; Weisberg & Newcombe, 2017). Piaget (1952) was one of the earliest proponents of sensorimotor activities as a means of constructing knowledge, defending the view that bodily actions are not separate from the mind. Memories of movement have proven to help students for future action (Tran et al., 2017), constituting "alternative channels of learning" that offer students easier understanding of educational material, as they connect the oral discourse with their learning environment (Hwang & Roth, 2011). In this way, students gain the ability to collect, compare, disagree with their peers' ideas, and adapt the information they receive through their personal interests. Most embodied digital environments support visualization of body movement as a function of learning goals to be achieved, influencing the learning process (Tran et al., 2017).

THE DIGITAL CLASSIFICATION TOOL "SORBET"

The digital tool used for this research is called "SorBET", as for "Sorting Based on Educational Technology". It is a software of the Educational Technology Laboratory (ETL) of National and Kapodistrian University of Athens, purposing to operate as a "game generator", supporting teachers with no prior programming knowledge, create their own categorization games (Grizioti & Kynigos, 2023). It was inspired by the interactive game "Koskino" (Kynigos et. al, 2010), where the players push and place objects falling at a constant rate in the appropriate categories using collaborative body movements. The prototype version was developed as part of a Master thesis (Giama, 2020) and it was further developed to include block-based programming and embodied interactions (Nikolaou, 2022). In "SorBET", users have the ability to play, modify, and design any type of classification games. As players, they need to make quick decisions, by classifying as many of the falling objects as possible into the correct categories, while achieving high levels in their score. As designers, they can design game elements such as density, speed, rules, object and category definitions, with block-based programming and database affordances. The field of objects and categories is up to the student to define, with no restriction to the topic. The classification model is not a one-to-one relationship but instead permits an object to be assigned to multiple categories, if it satisfies the criteria of the framework, resulting in a one-to-many relationship. Consequently, a category can overlap with or exclude another. This structure is intended to spark debate among players about the intersections or mutual exclusions of available categories based on object properties.

To promote embodied collaborative learning, we extended the initial "SorBET" tool, by incorporating gesture recognition as a means of categorizing objects. This enhancement is intended to improve the communication and interaction among players during the learning process, as well as to facilitate the development of strategies for classification and the interpretation of concepts. This new version allows players to handle and classify the falling objects using their palms, by recognizing hand gestures via users' web camera without any further equipment needed (Figure 1a). The current system's built-in interaction simulates the actual movement of a human palm, closing and opening to grasp and release an object, perceiving the closed fist/open palm gesture as a more intuitive and physical interaction type of system handling.

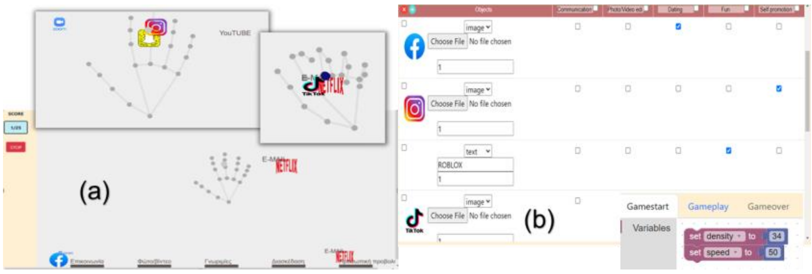

Figure 1: (a)Hand gesture tracking while playing the "App Game" in SorBET (b)Edit Mode

PILOT STUDY

To develop our understanding on children's classification and formation of meaning process, while playing and designing embodied classification games, we conducted a pilot study with secondary school students. The present study is the pilot part of a larger ongoing design-based research, studying the development of student 21st century skills in different domains through emerging technologies. The results will inform the redesign of the activities and the "SorBET" .

Context and Game

The study involved eight secondary school students (five boys and three girls) ages 13 to 17 working in groups of two. The duration was two hours for each group. Students experienced the kinesthetic version of the tool, by first playing and then modifying a subjective SorBET game called "App Game". The game involved classifying popular mobile applications, such as YouTube, Instagram, and Facebook, according to their primary way of use, to categories such as "communication", "self-promotion", "entertainment" and "dating" (Figure 1a,b). The applications were deliberately chosen so that the way they are used is ambiguous, with the aim of provoking debate among players about which category suits best, based on their personal experience. In each phase, one of the students would initially be the operator and the other one would observe and advise. Afterwards, the roles would be reversed, so that all participants could experience the activity equally. In the modification phase (Figure 1b), students had the opportunity to redesign the game according to their own criteria, by adding new applications or removing some of them, changing the object – class assignments and selecting the amount of times each application will display during the game. Most importantly, they had access to the original assumptions of the classifications, challenging themselves to think critically about the changes they would make, based on their own interpretation and applying logical reasoning.

To have a comprehensive view of student activity throughout the activities we collected multiple types of data. The most valuable of them, involved recorded group conversations, videos and photos to record students' hands and body movements, the games created by students along with their log files, and an individually semi-structured interview at the end of the study. We analysed the collected data in Atlas.ti software following the thematic analysis approach. First we triangulated the transcribed dialogues with the interviews, the photos and videos. Then two researchers analysed the data looking for critical episodes of student interaction with each other or with the tool that were relevant to the research questions. Since this approach is innovative and there was no known framework or coding scheme for these specific questions, the researchers followed a bottom-up abductive coding method for coding the incidents. After both researchers had coded the dialogues, they compared their codings and concluded to a final coding list from which they generalised the main themes of the results.

Initial Results

The following table shows the emergent codes and the documented relevant incidents as derived from the qualitative data analysis (Table 1).

Themes	**Codes**
Classification	“Comparison”,”Discrimination”, “Generalization”, “Intersection”, “Inclusion”, “Exclusion”
Usability & User Interface	“Changes - Additions”, “Difficulty”, “Aesthetics” , “Usability”
Students Engagement	“Creative Freedom”, ”Dedication”, “Disappointment”, “Personal Gratification”,
Social Context	“Competition”, “Mutual Support”, “Social Interaction”

Table 1: The codes resulting from the data analysis in Atlas.ti, per theme

The students played “AppGame" in pairs, without knowing that classification assignments were clearly subjective. It should be noted that in the initial design of the game, only the "one-to-one" category assignment was used in each application, in order to increase the difficulty, so that only one choice would be considered correct during the playing process. This resulted in students' low scores and cognitive dissonance about what the game considered as “correct”, but rich dialogues as students collaborated by classifying the applications with their palms. One example is the following utterance from a student while playing the App game that was coded as “Intersection”:

Student 3.1: “Instagram as communication and entertainment? But it's also a medium for photos and videos”.

In the design phase students appeared to have a better understanding of the underlying abstract concepts of the study. While editing the game, they discovered that certain sets of objects may correspond to more than one category, which completely altered their perspective on the classification process. Students also realized that one category does not exclude another or that some categories are inherent in others. In many cases students suggested changing the existing categories with other more specific or more inclusive ones. This is evident in the following incident from Group 4 that was also coded as “Exclusion/Inclusion”.

Student 4.1: “If it had "online lessons" it would fit, let's put it in...”

Student 4.2: “Should we add a new "music" category?...”

Student 4.1: “Should we change the title in the category "Photo/Video", make it only "Video"”

Giving students access to the game structure, sparked debate about the game's legitimacy. In most cases they modified the game based on their perspectives and view on how to use the applications.

As far as it concerns the game handling, the addition of gesture recognition for moving the objects to be classified had a genuine impact during the game process (Figure 2). Students engaged in an interactive classification experience using their palms which provided a more playful and interesting environment for them. This experience offered fertile ground for their interaction, collaboration, but also the formation of meanings about arbitrary concepts, such as the notions of classes and objects. One of the most interesting observations of the researcher who was present in the study, was the cooperation and mutual support that occurred between teammates. Although only one hand could be detected by the camera, the player who had the role of observer was actively involved by giving advice, encouraging and helping his teammate to sort using correct gestures:

Student 1.1: "This is how I did it, I think it works better, try it" (shows the movement of his hand to the teammate who was struggling).

Student 4.1: "Well done, you got it straight away, let's go!.....Close your hand and go like this to get in the center (shows how the camera should see the palm to detect the spot)".

While some characteristic replies in the interview regarding their experience of working together are the following (coded as "Social Interaction" and "Mutual Support"):

Student 3.2: "This game enhances cooperation because let's say that I didn't know a piece of information, but my teammate knew and help me and vice versa".

Student 2.1: "It would have been a lot of fun if we could both play together at the same time and I realized that as soon as I got involved".

Figure 2: Secondary students interact with the digital classification tool using hand gestures

DISCUSSION & CONCLUSIONS

The findings reveal that the tool provided students with a flexible and interactive environment that stimulated innovative thinking and enabled them to create their own categories and assignments. Through lively debates on the validity of classifications (Grizioti & Kynigos, 2023) and active manipulation of entities and categories, students gained a deeper connection with classification concepts such as comparison (Cao et al., 207), inclusion and exclusion, fostering their learning experience. By joining in arguments, explanations, and discussions, students actively engaged with the underlying concepts of the classification process, a fact that seemed to help them uncover hidden meanings and enhance their comprehension (Weisberg & Newcombe, 2017). The embodied interactions within the tool, both between students and between students and the system, confirms previous related studies (Johnson-Glenberg et al., 2014; Tran et al., 2017) as they seemed to play an important role in facilitating expression, meaning-making, and collaboration in a more concrete and tangible way (Fyhn, 2007; Barsalou, 2010; Shapiro 2011; Hwang & Roth, 2011; Weisberg & Newcombe, 2017). The presented pilot study will inform the iterative process of the design based research regarding the re-design of the activities and the digital tool in order to enhance students' game and learning experience. Some suggestions for improvement that came out of this research include, for example, changing the way objects are manipulated such as dragging instead of grabbing with the palm, simultaneous recognition of two or more palms, the ability to personalize the user interface (UI) and having more options available in blockly commands.

The exploration of classification as a versatile and higher-order skill holds significant value and warrants further investigation for advancing computational and mathematical reasoning. However, it is essential to ascertain whether the challenge of allowing students to explore, express, and combine computational and mathematical ideas through digital embodied classification games sufficiently fosters comprehensive skill development. While this pilot study did not specifically focus on individual mathematical skills, such skills are inherently embedded within the classification process itself. Therefore, extensive research and empirical evidence are needed to precisely define the key characteristics of digital classification and embodied cognition as an integrated approach for cultivating 21st-century computational and mathematical thinking skills. The insights gained from these studies will further contribute to the design and development of effective educational tools and strategies that promote higher-order thinking and skill development across various domains.

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