seminar.net
MEDIA, TECHNOLOGY & LIFELONG LEARNING
www.seminar.net

ISSN: 1504-4831 Vol 20, No 1 (2024) https://doi.org/10.7577/seminar.5700

Playful Computation: Teaching Computing Through Playful Learning

Surya Pasupuleti
University of Lapland
surya.t.pasupuleti@gmail.com

Marjaana Kangas
University of Lapland
marjaana.kangas@ulapland.fi

Abstract

This paper investigates students' experiences and teachers' attitudes towards playful computation: an innovative pedagogy that emphasizes playful learning to teach students information and computing technology. A pilot study was conducted at a Californian primary school during the summer, involving 84 students and 5 teachers engaging in creative and playful computing activities such as 3D printing, coding drones, redubbing audio, building computers, and music production. Student surveys, teacher interviews, and classroom observations were collected in mixed-methods research to provide multiple perspectives on the challenges and benefits of implementing the pedagogy.

Key findings indicate that playful computation significantly boosted student engagement and enjoyment, even surpassing student expectations. Teachers also expressed surprise at the increase in engagement as well as persistence, attributing this to the intrinsically rewarding nature of playful activities. Playful computation also promoted student self-expression and collaborative learning.

However, teachers expressed concerns about the practicality of implementing this pedagogy in standard educational settings due to existing structural constraints of aligning with academic standards. Classroom management and lack of established norms for play in this learning context also limited their lesson plans and implementations.

Supporting the existing literature on the benefits of playful learning, this research also suggests the need for further investigation into its role in facilitating flow and non-cognitive traits like grit. Investigating how playful computation impacts students' testable learning outcomes is also recommended as a necessary research direction to facilitate broader implementation in American classrooms.

Keywords: Computational Thinking, Playful Learning, Primary Education, 21st Century skills, Student Interest and Engagement, Information and Communication Technology (ICT)

Introduction

Since the turn of the century, equipping students with the skills requisite to navigate the ubiquity of information and computing technologies has become an increasingly critical challenge for global education. Early warnings date to the 1960s, with understanding programming envisioned as a prerequisite for employment and even societal participation (Kemeny, 1983). The discourse has subsequently expanded from concerns over 'digital divides' (Prensky, 2008) to analogizing programming literacy with the historical development of reading literacy (Vee, 2013). More contemporaneously, an UNESCO forum highlighted that we stand at the threshold of the Artificial Intelligence era, where AI literacy is fast becoming an indispensable skill for all citizens worldwide (Miao & Holmes, 2020).

The response in K-12 education has been to adopt a broader approach, emphasizing computational thinking (CT)—a framework that encompasses critical thinking and problem-solving skills applicable to both computing and non-computing contexts (Kong et al., 2022). Initially described as “solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science” (Wing, 2006), the term has since been broadened to include multiliteracies that reflect the sociocultural and creative aspects of computational fluency (Kafai et al., 2019; Kaspersen et al., 2021). These skills are foundational for innovating and creating new knowledge using computing technology (Silander et al., 2022). Computational empowerment expands on these concepts further to contend that children should be empowered through participatory design in addition to learning CT and technological proficiency (Dindler et al., 2020).

Despite the recognized importance of teaching about computing technologies, teachers globally express a lack of confidence in their own computing abilities and often hesitate to integrate them into their teaching (Wang et al., 2021). The current state of Computer Science education in United States K-12 public schools remains insufficient, with notable deficiencies in access and participation especially at the elementary and middle school level (Code.org, & CSTA, & ECEP Alliance, 2022). This inconsistent access to teaching on computing at the primary and secondary levels has been identified as a significant factor contributing to the alarming lack of diversity in Computer Science college courses and the tech workforce (Cheryan et al., 2017; Hinton, 2016).

Thus, despite increasingly recognized importance, there remain notable gaps in research exploring pedagogical approaches in primary and secondary education. In response to these challenges, this paper introduces 'playful computation' as an innovative pedagogy, adapting the principles of playful learning to the teaching of computing in primary and early secondary education. It investigates the implementation of playful computation in a summer program within an American school district, focusing on student experiences and teacher attitudes.

Research Questions

Due to the study's exploratory nature, the research questions were formulated during the data collection and classroom observation phases. The emergent research questions were:

1. What were the students’ prior expectations for the program, and how did these compare with their actual experiences?

2. In what ways did teachers' attitudes towards playful computation evolve during the program?

3. What were the perceived benefits and challenges of integrating playful computation?

Theoretical Background

Playful learning (PL), a technology-enriched pedagogy, captivates learners with interactive and enjoyable activities, encouraging exploration and experimentation. It is a hands-on, mind-on, body-on form of active participatory learning. In playful learning, learners can use their imaginations, learn from mistakes, and have adventures with new aspects of their learning environments (Kangas, 2010b; Kangas et al., 2017; Ferguson et al., 2019; Hassinger-Das et al., 2017). Playful learning also emphasizes the attitude of playfulness and quality of play that is characterized by the presence of significant action, embodiment, collaboration, creativity, narration, insight, and emotion (Kangas, 2010b). In this regard, playful computation can have substantial overlap while remaining distinct from other computing pedagogies such as creative coding and game-based learning. In turn, this broader range of creative and ludic activities offers a more flexible framework for teachers to adapt to their classroom environments.

The underpinning of PL in pedagogy is rooted in constructionism and socioculturally oriented theories of learning (Kangas, 2010b). Constructionism posits that students learn optimally through construction of personal meaning artifacts for sharing and reflection (Papert & Harel, 1991). Constructionist pedagogy is not new to teaching computation as it influenced the development of the programming language Logo in 1967 (Papert, 1980). The further evolution of these ideas is evident in the concepts of creative coding, using computer programming primarily for creative expression (Peppler & Kafai, 2005), and the development of the educational programming language of Scratch (Resnick et al., 2009).

Sociocultural theories emphasize learning in interaction and understand it as an authentic interplay among individual agency, socially structured activities, and technological tools (Ludvigsen et al., 2010). Social constructivism (Amineh & Asl, 2015) and sociocultural theories (Säljö, 2004) both stress the collective construction of knowledge through interaction, which also underpins the co-creative elements of playful computation. Coding and CT are thus seen as communal practices, necessitating pedagogy that is embedded in sociodigital processes (Kafai, 2006). In learning through play, students actively co-create knowledge (Kangas, 2010b) and reconfigure their understanding of concepts, a process that aligns with the trialogical approach to knowledge creation (Paavola & Hakkarainen, 2014).

Research shows that children understand foundational computational concepts in media creation but often struggle with abstraction (Meerbaum-Salant et al., 2013). However, educational games that scaffold abstract concepts can enhance mastery over these challenging areas (Rose et al., 2020). Such games also facilitate learner engagement and activate key neurofunctional areas related to motivation and emotion (Greipl et al., 2021).

Critical to the implementation of playful computation is the fostering of teacher engagement and competencies. In playful learning, teachers have multifaceted and dynamic roles in integrating play into curriculum-relevant learning outcomes (Hyvonen, 2011; Kangas, 2010a). Thus, effective implementations require from instructors a sense of ownership (Kangas et al., 2017) and multiple competencies in pedagogical, technological, collaborative, and creative components (Nousiainen et al., 2018). While the theoretical underpinnings of playful learning are well established, playful computation and its practical application to CT education in primary and secondary education require further exploration.

Methods

Research Context

The study was conducted in a Californian public school district's three-week summer technology program. Eighty-four students, poised to enter grades 4 through 8, were engaged in playful computation by five participating teachers. Each class consisted of approximately fifteen classroom hours (including recess) and organized around the understanding and creative application of different computing technologies. The themes of the classes were 1) Physical Computing and Electronics, 2) Coding and Robotics, 3) Music Production, 4) 3D Design and Printing, and 5) Additional Dialogue Replacement (ADR). Brief descriptions of the five classes are presented in Figure 1 and in the teacher profiles section.

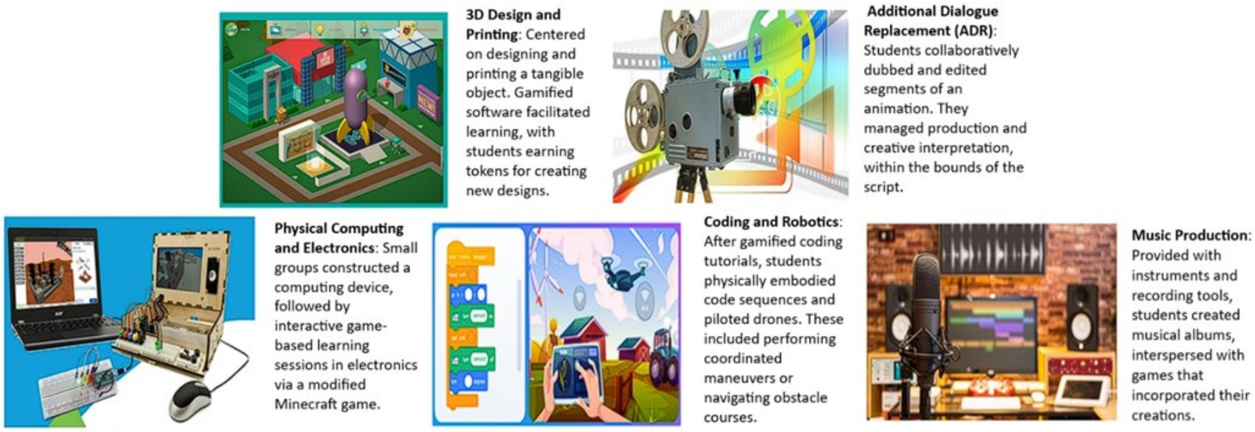

Figure 1: Description of the themes in the classes during the technology program

Researcher Role

The summer program was a school district-initiated project. The programs were structured primarily by the district's technology coordinator and individual teachers. Prior to the start of the course, teachers had two professional development days where they planned and familiarized themselves with the contents of the course. The technology coordinator additionally provided supplementary training with regards to the technological tools.

During this class planning period, teachers were shown a brief presentation on playful computation by the primary author. They also had the opportunity to interact individually in a dialogue on possible implementations of playful computation in this planning stage. During the summer program, the primary author then took on the role of classroom observer.

Teacher Profiles

The participating teachers, who opted in voluntarily, shared a belief in the importance of integrating computational thinking (CT) into the K-12 curriculum. However, their familiarity with playful learning varied prior to the program. Brief profiles and a description of how they taught their respective courses are as follows:

Teacher A (3D Printing): A young and recently graduated teacher, she was proficient with using media in education but had no previous experience teaching computing. Students used the gamified software of Makers' Empire to design and print their own 3D objects. Students could also create 3D mazes and most found it highly engaging to create challenging levels for their peers to navigate. Recognizing it as both potentially motivating and disruptive, the teacher used it as a reward at the end of class. However, beyond the gamified software, other elements and characteristics of playful computation were less well integrated.

Teacher B (Additional Dialogue Replacement): An experienced teacher with a robust understanding of computing, he was also pursuing further professional development to be a subject matter expert in it. He further regularly incorporated gamification and game-based learning into his prior teaching. Classes typically began with a collaborative problem-solving game. The course was structured around a project where students collectively redubbed the audio of an existing animation, practicing both recording and editing along with project management. All the characteristics of playfulness were quite prominent, with the teacher especially encouraging and demonstrating to students how to embody roles drastically different from themselves or do multiple emotional interpretations.

Teacher C (Physical computing): An older and highly experienced teacher, she was quite apprehensive about her proficiency in teaching computing. However, she had some prior experience in teaching the subject through extracurricular activities. She was also the most apprehensive about the disruptive elements of playfulness. The course was structured around the Piper Computer Kit, where students in groups of 2 followed a blueprint to construct a Raspberry Pi computing device in a wooden briefcase. Then through a custom version of Minecraft, they learned how to wire and code different input/output controls to progress in the game. Due to the complex nature of the project, the teacher acted primarily as a facilitator focused on organizing and maintaining a good learning environment. However, she greatly favored encouraging student problem-solving remarking that as students were highly motivated to play Minecraft, their confusion and frustration could be productively channeled into insight and creativity rather than lapsing into boredom and apathy.

Teacher D (Robotics): An older and highly experienced Computer Science educator with an excellent grasp of teaching computing and computational thinking. Though familiar with playful learning, he previously seldom employed it, perceiving it as less suitable for older students and abstract subjects. This perspective shifted during the teaching of the course as he adopted more playful implementations as well as recognized those that were already extant in his pedagogy. One such example of the latter was beginning every class with a science-fiction exercise where students were invited to collaboratively imagine future computing technologies and how they would interact with them. The class itself was structured around coding drones to fly autonomously. Students practiced their coding through gamified lessons and simulations. Prior to flying drones, they also practiced embodiment by 'coding a partner' to enact the exact drone instructions. Play scenarios were encouraged such as in making the drones dance or navigating an indoor obstacle course reimagined as a mountain rescue operation.

Teacher E (Music production): A moderately experienced science teacher, she was also pursuing further professional development in teaching computing. Pedagogically experimentative, she had previous experience in teaching science through play that emphasized embodiment, creativity, and collaboration. Students in the class created their own albums through editing and splicing audio samples and recording their own music. They also did simple image editing to generate album art. Beyond facilitating student creativity, the teacher frequently interspersed games into the class. One example was to have students play musical chairs with music they created, eliciting action and embodiment but also collaboration as they recognized their peers' stylings. Other games involved identifying movies from brief snippets of their soundtracks, or breaking down how music evokes emotions.

4. Data Collection & Analysis

To triangulate data and gain a nuanced understanding of playful computation's impact, the study utilized a mixed-methods approach (Johnson & Christensen, 2020).

Student Measures

Participating students completed a pre- and post-survey at the start and conclusion of the three-week program. The pre-survey consisted of 6 questions based on the Likert scale and an additional open-ended prompt to describe their learning goals. The questions for student expectations were based on a scale concerning Finnish students' programming motivation in the International Computer and Information Literacy Study (Fagerlund et al., 2022; Fraillon et al., 2019). Students were prompted to rate on a Likert-scale of 1-4 (strongly agree to strongly disagree) on why they chose to participate in the summer program. Three questions corresponded to (1) anticipation of interest or enjoyment (Cronbach's α = 0.93), two questions corresponded to (2) perceived importance or usefulness of what will be taught (Cronbach's α = 0.80). Additionally, students were asked if someone else such as a parent or guardian thought it was important for them to participate. This measure was included to identify students who primarily disagreed on being interested in or valuing the subject but may have instead been obliged to attend due to external pressures.

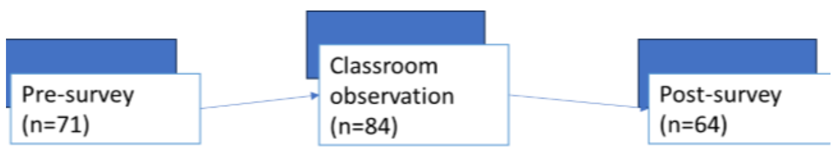

Figure 2: Number of student participants across the duration of the study

The post-survey collected student experiences through 5 questions based on the Likert scale, and 3 open-ended prompts. Students were asked to rate their enjoyment of the program, and their willingness to participate again in both the summer and during the academic year. They were also asked to rate whether what they learned was exciting, and the value and usefulness of what they learned. In the post-survey, questions were each followed by an open-ended prompt for students to further elaborate on their ratings.

Classroom Observations

Observation notes were collected by the primary author within the five participating classrooms, corresponding to 71 hours of observation cumulatively. During the process of collecting these notes, the primary author also actively interacted with both students and teachers, including being invited to participate in some games or activities.

Teacher Interviews

Semi-structured interviews were conducted with the five participating teachers both prior to the start of the program and at the conclusion of it. The pre-interview assessed the teachers' prior familiarity and attitudes towards both playful learning and teaching computing, their expectations towards implementing playful computation into their pedagogy, and student learning goals. During the post-interview, teachers were asked to reflect on their overall experience and how playful learning impacted their teaching approach, student learning outcomes and engagement, and any additional challenges implementing the pedagogy posed. Cumulatively, the interviews were 179 minutes long, with the average pre-interview lasting 16 minutes and the average post-interview just under 20 minutes. In size 12, single-spaced Times New Roman font, the interviews were collectively 56 pages long with a word count of 24,490.

Analysis

Though less statistically powerful, the non-parametric Wilcoxon test was utilized due to its suitability in comparing pre- and post- results when the data does not have a normal distribution. Cronbach's alpha tests were conducted to verify the internal reliability of the subscales in the pre-survey. Statistical tests were performed within IBM's SPSS Statistics software and jamovi, an open-source software based on the R programming language.

Thematic analysis (Braun & Clarke, 2006) was performed on qualitative data consisting of student responses to open-ended prompts, classroom observation notes, and teacher interviews. Following manual transcription of the interviews, all qualitative data was imported into NVivo qualitative data analysis software. For the less complex student responses, content analysis and the generation of graphical representations such as world clouds was first conducted for each prompt. Then themes were extracted to contextualize the quantitative responses provided by the students in the surveys.

Figure 3: Word cloud of students' favorite activity (grouped by synonym)

The observation notes and interview transcripts were open coded in an iterative manner allowing distinct themes to emerge. The data was then reorganized under these themes with the ones pertinent to the research questions and relevant across multiple classroom contexts further analyzed.

Research Ethics

The study follows the ethical standards of the Finnish Advisory Board on Research (https://www.tenk.fi). All the participants joined voluntarily in the study. The study was planned with ongoing stakeholder dialogue. Teacher consent was secured for participation in the study and audio recording in accordance with the state of California's privacy laws. Data storage protocols were also transparently communicated to stakeholders. Interviews are encrypted and stored securely on the university's servers. Analysis was conducted on anonymized transcripts, ensuring participant confidentiality. Student data was only collected in the form of surveys, which were anonymized with unique IDs assigned to each participant. No audio or visual recordings were made of students to further protect their privacy.

Results

Student Expectations and Experiences

Students, having self-enrolled, had high expectations for the summer program with the majority strongly agreeing that they're excited for the program and that they enjoy being creative with technology and computing devices.

Subscale	*Item*	*Percentage distribution of responses*			
		1 – strongly agree (%)	2 – agree (%)	3 – disagree (%)	4 – strongly disagree (%)
Interest / enjoyment	A. I'm excited to learn this	50.7	28.2	14.1	7.0
	B. I think what we'll learn will be fun	46.5	33.8	12.7	7.0
	C. I enjoy being creative with technology	60.6	21.1	12.7	5.6
Importance / value	D. I think it's important to learn this	40.8	39.4	14.1	5.6
	E. It's valuable to know how to be creative with technology	47.9	35.2	11.3	5.6
	F. Someone else thought it was important for me to learn this	36.6	31.0	16.9	15.5

Table 1: Descriptive statistics of student expectations

Likewise, students reflected very positively on their experiences with the program with most enjoying it, finding value, and wanting to participate again. Thematic analysis of students' open-ended responses highlighted the pivotal role of integrating play and creativity in enhancing student engagement and fostering an environment that encouraged intellectual exploration. The personalized creative elements appear to have resonated most strongly, with the majority highlighting making or building activities as their favorite experiences. There was slightly less enthusiasm for doing this in the regular academic year. However, this may in part be due to the ambiguous wording of the question, with students' open-ended responses evaluating it as an after-school program that would reduce their free time.

Item	*Percentage distribution of responses*			
	1 – strongly agree (%)	2 – agree (%)	3 – disagree (%)	4 – strongly disagree (%)
A. I enjoyed participating in [course]	65.6	32.8	1.6	0
B. I would like to participate in [course] again	50.0	35.9	9.4	4.7
C. I would like to do something similar during regular school	46.9	39.1	9.4	4.7
D. I learned exciting things	65.6	26.6	6.3	1.6
E. What I learned is valuable or useful to me	59.4	26.6	9.4	4.7

Table 2: Descriptive statistics of student experiences

A substantial group of students had no differences in their experiences from their expectations with most of these being 'strongly agree' in both responses. Rather, the uplift in excitement and enjoyment was predominantly among students with lower expectations who reported their experiences exceeded their initial outlook. Notably, several students remarked that while they do not enjoy school, they did enjoy this. Overall, these differences in excitement and engagement were statistically significant with a relatively large effect size.

Pre-survey	**Post-survey**	**Wilcoxon W**	**p**	**Effect Size**	
I'm excited to learn this Median: 1, Mean: 1.63	I learned things that I'm excited to use Median: 1, Mean: 1.37	165 [a]	0.016	Rank biserial correlation	0.571
I think what we will learn will be fun Median: 1, Mean: 1.73	I enjoyed participating in Tech Academy Median: 1, Mean: 1.33	182 [a]	0.003	Rank biserial correlation	0.733

Pre-survey	Post-survey	Wilcoxon W	p	Effect Size	
I think it is important to learn this Median: 2, Mean: 1.76	What I learned is valuable or useful to me Median: 1, Mean: 1.63	286 [b]	0.240	Rank biserial correlation	0.228

Note. H_a $\mu_{\text{Measure 1 - Measure 2}} \neq 0$

[a] 31 pair(s) of values were tied

[b] 21 pair(s) of values were tied

Table 3: Wilcoxon test comparing expectations vs experiences

However, five students did indicate that their excitement or enjoyment was less than what they anticipated. In explaining their answer, three of them highlighted that what they were learning didn't feel relevant outside the summer program. Other students likewise indicated this when answering the value and usefulness of what they learned. This is one likely reason for the lack of statistically significant change in those pre- and post- attitudes. Near the end of the summer program, one of the students had asked if his older brother could speak about his work in coding drones that suppress wildfires. His brief description thoroughly captured the imaginations of that classroom, with Teacher D wishing other students also had the experience so they also understand how the world is changing and that "these occupations exist, and they're all within their grasp." This could be one potential avenue to help ground the playful, imaginative, and creative activities of playful computation into the realm of the relevant and possible 'real world' scenarios.

Teachers' perceptions and attitudes towards playful computation

The integration of play and creativity within the educational framework was unanimously seen by the teachers as a transformative approach that significantly enhances student engagement and facilitates learning of computing. This framework created an intellectually stimulating environment that encouraged exploration and innovation. Despite the significant variance in how teachers implemented playfulness, three themes were consistently expressed on its value to learning:

Engagement: The teachers observed that playful learning significantly increased student engagement. They attributed this to the student-driven learning aspect, as students could self-direct their pace and learning direction. The personal relevance of creative outputs and the rewarding nature of play were also noted as key factors in maintaining elevated levels of student interest and participation.

Self-expression: A playful learning environment allowed students to express themselves more freely. Teacher D contextualized this as “when the kids relax, they can be more of themselves. With middle schoolers, often I see the second or third grader in the kids’ faces when they’re having fun, and they lower these defenses that they build up. [They] can actually just be there enjoying themselves and not worry about middle school drama issues.” Teachers B & E echoed sentiments that the teenaged students particularly appear to have benefited from a playful approach helping lower social anxieties and participate enthusiastically in a manner they typically did not. While an observer, students also consistently approached the primary author to share their work, increasing in frequency as they became more accustomed to his presence. This was especially notable in the music production class with many students eager to have anyone and everyone available to listen to their tracks. Likewise, students’ 3D printed objects were eagerly passed around both in and out of the classroom during breaks.

The ability to create and share in alternative ways also provided otherwise shy students with a means to express themselves, facilitating connections between students and between students and teachers. The teachers reported that in these environments, students were more likely to collaborate and seek help from peers without fear of rejection or mockery; Teacher C noted that this was bi-directional as the student asking for help rarely seemed to be concerned whether it reflected negatively on their intelligence or competencies while the helper was often enthused to share their creativity and skills.

Persistence: All teachers remarked on the notable persistence displayed by students engaged in playful learning activities. They were surprised by the levels of patience and hard work students demonstrated, even during less engaging or frustrating parts of the course. For example, during observation of the physical computing classes, it became evident that constructing the device would be especially challenging to younger or less meticulous students. Seemingly small errors could lead to larger issues, and in one instance a student burst into tears upon realizing that by orienting the LCD screen incorrectly at the very start of his build, he’d need to redo a great deal of work. Yet, in every instance, after a combination of gathering themselves and consolation by peers and teachers they rectified their mistakes and finished their Piper computers. Likewise, Teacher A noted that most students struggled with printing their first 3D object, adding “a lot of them were frustrated, but they’re so relieved once they finally get it. I think it’s more motivating when they have those failures and [overcome them].” The observable frequent and total absorption of learners into their tasks and overcoming challenges may have been representative of them being in a flow state. Teacher D humorously quoted Mary Poppins, saying 'a spoonful of sugar helps the medicine go down,' to illustrate how rewarding tasks made learning more enjoyable in an otherwise typically challenging and frustrating subject.

Teacher B meanwhile contrasted the typical disinterest or anxiety when learners are informed that they must struggle through a challenging concept due to standards dictating “they have to know XY and Z by the end of the year versus them going and being frustrated because they played a game or activity, and screaming ‘well, help me learn this so I can do better!’” All five teachers remarked on students' desire to overcome frustrating obstacles in pursuit of longer-term goals. This combination of persistence and passion typically characterizes the non-cognitive trait of grit (Duckworth et al., 2007).

Benefits and challenges of integrating playful computation

The teachers oscillated between roles as facilitators, mentors, and instructors, highlighting the need for adaptability in teaching styles. This adaptability was crucial for fostering student autonomy while providing the necessary guidance and support. Continuous professional development and reflective practice were identified as essential for the teachers to effectively meet the diverse needs of their students.

Despite the positive experiences with playful learning, the teachers identified several challenges in its implementation, particularly in the context of the regular academic year. Teacher C described their dilemma in moving away from a predominantly lecture-based pedagogy, "every year, especially at this time, [I think], how do I change it? How do I make it less boring and more playful, hands-on interactive. But it's hard to dedicate time to that when you have all the standards barreling down on you and feeling like you're behind from the get-go. […] Just in the first week of school, you are already behind." Teachers B & E, who regularly implemented aspects of playful learning in their pedagogy, stated that time constraints nevertheless often forced them to revert to lecturing. Teacher B further contextualized that both teachers and students are disappointed when this occurs, yet it is understood as part of the reality of education in this context.

Teachers also frequently addressed the challenges of managing classroom behavior while encouraging a dynamic and interactive learning environment, striving to strike a balance between discipline and freedom. Multiple teachers highlighted how students lacked the necessary contexts for proper behavior in a playful classroom; Teacher E pointed out "if they had less structure and more play at younger ages, it would be more normal for them here" while Teacher D opined:

> I'll find you try to do an activity, sometimes it's kind of hard to rein kids in and do playful learning in a way that doesn't devolve into just being a classroom management issue. And that's because they either don't get enough play or don't know how to self-regulate. (Teacher D)

Teachers acknowledged that they must account for this unfamiliarity in their lesson planning, restricting their ability to let students explore in an unstructured manner. The responsible use of technology was also raised as a concern, both with regards to safety in cases such as drones as well as the greater opportunities for distraction. The teachers expressed concerns over their ability to distinguish between productive and unproductive play, especially when including computing devices that some students may have greater familiarity with than them. Thus, a broader shift in educational culture to embrace play as a valuable component of the classroom learning process with its own etiquette may be first required for teachers to feel less anxious about implementing playful computation.

Discussion

The high levels of enjoyment and engagement that students reported in this study align with existing literature that underscores the positive impact of playful learning on student satisfaction (Kangas et al., 2017) and the effectiveness of game-based learning in fostering engagement (Shu & Liu, 2019). For preschoolers, playful learning with a programmable robot was found to encourage development of coding logic and physical activity (Helijakka & Ihamäki, 2019). Although play-based learning is increasingly recognized in early childhood education in the US (Taylor & Boyer, 2020), the application of play and playfulness in higher grade levels requires further advocacy and professional development to ensure can integrate these methods effectively. This study's findings contribute to the growing body of evidence suggesting that playful learning can be a powerful pedagogical approach across various age groups, not just in early childhood education (Whitton, 2022).

Particularly noteworthy was the observed perseverance among students engaged in playful learning activities. This aligns with the emphasis on perseverance in problem-solving as outlined in the United States Common Core standards for mathematics (Star, 2015). The positive association with struggle, supported by playful learning, may offer a valuable strategy for educators aiming to cultivate the non-cognitive traits of grit and perseverance, which are increasingly recognized as crucial for success in the 21st century (Duckworth et al., 2007).

Further, individuals in a flow state are considered to experience the following: a clear goal-oriented focus, loss of self-consciousness, intrinsic motivation and enjoyment of an experience for its own sake (Nakamura & Csikszentmihalyi, 2002). The teachers' perceptions indicate that the high learner engagement and the student-driven aspects of playful computation may also facilitate learners operating in a flow state. This pedagogy, by facilitating collaborative learning, also expands the learners' Zone of Proximal Flow to tackle greater challenges with greater skill due to opportunities for teacher scaffolding and social learning from peers (Basawapatna et al., 2013). While the role of playfulness in alleviating student social anxiety was an unexpected finding for this study, there is an extensive body of evidence on how play reduces general anxiety in medical and therapeutic research (Barnett & Storm, 1981; Li et al., 2016) as well as play-based therapies being used in classrooms for social anxiety (Atayi et al., 2018). Playful learning has also been found to be an effective tool in enhancing social-emotional literacy (Helijaka et al., 2021).

However, a clear tension exists between the desire to implement playful learning and the pressure to meet curricular standards. This reflects a broader challenge within the education system, where the demands of standardized testing and curricular benchmarks often limit the adoption of play-based approaches (Bubikova-Moan et al., 2019). It is also evident that additional development of the pedagogy is required to facilitate adoption into American primary and lower secondary education.

Limitations

One substantial limitation to the study is that the items in the pre- and post- survey didn't correspond perfectly to each other. This imprecision in the wording and possibilities for different interpretations introduces potential confounds when comparing expectations and experiences – particularly when we contrasted student anticipation of 'fun' with experienced 'enjoyment'. Furthermore, this sample is unrepresentative of a typical classroom due to the self-selection in a summer program, limiting the generalizability of the findings. It is endeavored however that by including classroom observations, teacher interviews, and student survey responses, a cohesive narrative emerges of the student perspective in playful computation.

As researchers, we informed and provided resources for the teachers' autonomous course planning. As such, there were notable differences in teachers' implementations of playful computation pedagogy. However, this approach also provides valuable insight into teachers' preferences and challenges such that pedagogy can be further iterated upon in future research.

Conclusions

Consistent with prior research on similar pedagogical approaches, playful computation significantly enhances student engagement, enjoyment, and perseverance in learning activities. Here, students experienced these more than they anticipated, and teachers were also pleasantly surprised. Teachers likewise highlighted the positive effects of playful learning on students: they were engaged, persistent, and collaborative. Research on grit and perseverance, as well as the flow state in playful learning are intriguing directions for future research. It is also critical to investigate more thoroughly why some students remained unengaged or felt disconnected from 'real world' relevance, and how the pedagogy can be better adapted to remedy that.

However, most critically, it also brought to light the challenges educators face when attempting to integrate these approaches within the constraints of standard curricula and the traditional academic calendar. The findings underscore the need for educational systems to offer support and flexibility in integrating playful learning strategies, which may include professional development, curriculum adjustments, and policy reforms. The pedagogy must also consider and adapt to the importance of standardized testing and the urgency teachers feel in 'teaching to the test' in the American context.

However, learners are naturally active, curious, and playful (e.g. Bird & Holmwood, 2018) and playfulness is a fundamental aspect of human nature and individual learning that should be better acknowledged in educational design. We thus suggest it as an exciting direction for future research to examine how a mind-on, hands-on, body-on playful approach can enhance students' testable learning outcomes as well as overall development.

References

Amineh, R. J., & Asl, H. D. (2015). Review of Constructivism and Social Constructivism. *Journal of Social Sciences, Literature and Languages*, *1*(1), 9–16.

Atayi, M., Hashemi Razini, H., & Hatami, M. (2018). Effect of cognitive-behavioral play therapy in the self-esteem and social anxiety of students. *Journal of Research and Health, 8*(3), 278–285. https://doi.org/10.29252/jrh.8.3.278

Barnett, L. A., & Storm, B. (1981). Play, pleasure, and pain: The reduction of anxiety through play. *Leisure Sciences, 4*(2), 161–175. https://doi.org/10.1080/01490408109512958

Basawapatna, A. R., Repenning, A., Koh, K. H., & Nickerson, H. (2013). The zones of proximal flow: Guiding students through a space of computational thinking skills and challenges. *Proceedings of the Ninth Annual International ACM Conference on International Computing Education Research*, 67–74. https://doi.org/10.1145/2493394.2493404

Bird, D. & Holmwood, C. (2018). Rediscovering the playful learner. In J. Taylor & C. Holmwood, C. (Eds.). *Learning as a creative and developmental process in higher education: A therapeutic arts approach and its wider application*. Routledge

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3, 77–101. https://doi.org/10.1191/1478088706qp063oa

Bubikova-Moan, J., Næss Hjetland, H., & Wollscheid, S. (2019). ECE teachers' views on play-based learning: A systematic review. *European Early Childhood Education Research Journal*, 27(6), 776–800. https://doi.org/10.1080/1350293X.2019.1678717

Cheryan, S., Ziegler, S. A., Montoya, A. K., & Jiang, L. (2017). Why are some STEM fields more gender balanced than others? *Psychological Bulletin, 143*(1), 1–35. https://doi.org/10.1037/bul0000052

Code.org, & CSTA, & ECEP Alliance. (2022). *2022 State of Computer Science Education: Understanding Our National Imperative*. https://advocacy.code.org/stateofcs

Dindler, C., Smith, R., & Iversen, O. (2020). Computational empowerment: Participatory design in education. *CoDesign*, 16, 1–15. https://doi.org/10.1080/15710882.2020.1722173

Duckworth, A. L., Peterson, C., Matthews, M. D., & Kelly, D. R. (2007). Grit: Perseverance and passion for long-term goals. *Journal of Personality and Social Psychology, 92*(6), 1087–1101. https://doi.org/10.1037/0022-3514.92.6.1087

Fagerlund, J., Leino, K., Kiuru, N., & Niilo-Rämä, M. (2022). Finnish teachers' and students' programming motivation and their role in teaching and learning computational thinking. *Frontiers in Education*, 7. https://doi.org/10.3389/feduc.2022.948783

Ferguson, R., Coughlan, T., Egelandsdal, K., Gaved, M., Herodotou, C., Hillaire, G., Jones, D., Jowers, I., Kukulska-Hulme, A., McAndrew, P., Misiejuk, K., Ness, I. J., Rienties, B., Scanlon, E., Sharples, M., Wasson, B., Weller, M., & Whitelock, D. (2019). *Innovating Pedagogy 2019: Open University Innovation Report 7.* The Open University. https://ou-iet.cdn.prismic.io/ou-iet/b0fbe67d-3cb3-45d6-946c-4b34330fb9f9_innovating-pedagogy-2019.pdf

Fraillon, J., Ainley, J., Schulz, W., Friedman, T., & Duckworth, D. (2019). *Preparing for Life in a Digital World: IEA International Computer and Information Literacy Study 2018 International Report*. Springer International Publishing. https://doi.org/10.1007/978-3-030-38781-5

Greipl, S., Klein, E., Lindstedt, A., Kiili, K., Moeller, K., Karnath, H.-O., Bahnmueller, J., Bloechle, J., & Ninaus, M. (2021). When the brain comes into play: Neurofunctional correlates of emotions and reward in game-based learning. *Computers in Human Behavior*, 125, 106946. https://doi.org/10.1016/j.chb.2021.106946

Hassinger-Das, B., Toub, T. S., Zosh, J. M., Michnick, J., Golinkoff, R., & Hirsh-Pasek, K. (2017). More than just fun: A place for games in playful learning / Más que diversión: El Lugar De Los juegos reglados en El Aprendizaje lúdico, Infancia Y Aprendizaje. *Journal for the Study of Education and Development*, 40, 191–218. https://doi.org/10.1080/02103702.2017.1292684

Heljakka, K., Lamminen, A., & Ihamäki, P. (2021). A Model for Enhancing Emotional Literacy through Playful Learning with a Robot Dog. *2021 International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME)*, 1–7. https://doi.org/10.1109/ICECCME52200.2021.9590996

Heljakka, K., & Ihamäki, P. (2019). *Ready, Steady, Move! Coding Toys, Preschoolers, and Mobile Playful Learning. Learning and Collaboration Technologies. Ubiquitous and Virtual Environments for Learning and Collaboration* (pp. 68–79). Springer International Publishing. https://doi.org/10.1007/978-3-030-21817-1_6

Hinton, M. (2016). Diversity gaps in Computer Science education. *Education Week, 36*(10), 5–5.

Hyvonen, P. T. (2011). Play in the School Context? The Perspectives of Finnish Teachers. *Australian Journal of Teacher Education*, *36*(8). https://doi.org/10.14221/ajte.2011v36n8.5

Johnson, B., & Christensen, L. (2020). *Educational Research: Quantitative, Qualitative, and Mixed Approaches* (7th ed.). Sage.

Kafai, Y. (2006). Playing and Making Games for Learning: Instructionist and Constructionist Perspectives for Game Studies*. Games and Culture, 1*(1), 36–40. https://doi.org/10.1177/1555412005281767

Kafai, Y., Proctor, C., & Lui, D. (2019). From Theory Bias to Theory Dialogue: Embracing Cognitive, Situated, and Critical Framings of Computational Thinking in K-12 CS Education. *ICER '19: Proceedings of the 2019 ACM Conference on International Computing Education Research*. http://dx.doi.org/10.1145/3291279.3339400

Kangas, M. (2010a). Creative and playful learning: Learning through game co-creation and games in a playful learning environment. *Thinking Skills and Creativity*, *5*(1), 1–15. https://doi.org/10.1016/j.tsc.2009.11.001

Kangas, M. (2010b). *The school of the future: Theoretical and pedagogical approaches for creative and playful learning environments*. University of Lapland. https://urn.fi/URN:NBN:fi:ula-2011291055

Kangas, M., Siklander, P., Randolph, J., & Ruokamo, H. (2017). Teachers' engagement and students' satisfaction with a playful learning environment. *Teaching and Teacher Education*, 63, 274–284. https://doi.org/10.1016/j.tate.2016.12.018

Kaspersen, M. H., Graungaard, D., Bouvin, N. O., Petersen, M. G., & Eriksson, E. (2021). Towards a model of progression in computational empowerment in education. International *Journal of Child-Computer Interaction*, 29, 100302. https://doi.org/10.1016/j.ijcci.2021.100302

Kemeny, J. G. (1983). The Case for Computer Literacy. *Daedalus*, *112*(2), 211–230. https://www.jstor.org/stable/20024860

Kong, S.-C., Abelson, H., & Kwok, W.-Y. (2022). Introduction to Computational Thinking Education in K–12. In S.-C. Kong & H. Abelson (Eds.), *Computational Thinking Education in K–12: Artificial Intelligence Literacy and Physical Computing* (p. 0). The MIT Press. https://doi.org/10.7551/mitpress/13375.003.0002

Li, W. H. C., Chung, J. O. K., Ho, K. Y., & Kwok, B. M. C. (2016). Play interventions to reduce anxiety and negative emotions in hospitalized children. *BMC Pediatrics, 16*(1), 36. https://doi.org/10.1186/s12887-016-0570-5

Meerbaum-Salant, O., Armoni, M., & Ben-Ari, M. (Moti). (2013). Learning computer science concepts with Scratch. *Computer Science Education*, *23*(3), 239–264. https://doi.org/10.1080/08993408.2013.832022

Miao, F., & Holmes, W. (2020). *International Forum on AI and the Futures of Education, developing competencies for the AI Era, 7-8 December 2020: Synthesis report*—UNESCO Digital Library. https://unesdoc.unesco.org/ark:/48223/pf0000377251

Nakamura, J., & Csikszentmihalyi, M. (2002). The concept of flow. In C. R. Snyder & S. J. Lopez (Eds.) *Handbook of positive psychology* (pp. 89–105). Oxford University Press.

Nousiainen, T., Kangas, M., Rikala, J., & Vesisenaho, M. (2018). Teacher competencies in game-based pedagogy*. Teaching and Teacher Education*, 74, 85–97. https://doi.org/10.1016/j.tate.2018.04.012

Paavola, S., & Hakkarainen, K. (2014). Trialogical Approach for Knowledge Creation. In S. C. Tan, H. J. So, & J. Yeo (Eds.), *Knowledge Creation in Education* (pp. 53–73). Springer Singapore. https://doi.org/10.1007/978-981-287-047-6_4

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

Papert, S., & Harel, I. (1991). Situating Constructionism. In S. Papert & I. Harel (Eds.) *Constructionism* (pp. 1–11). Praeger.

Peppler, K. A., & Kafai, Y. (2005). *Creative Coding: Programming for Personal Expression* [Conference Paper]. The 8th International Conference on Computer Supported Collaborative Learning, Rhodes.

Prensky, M. (2008). *Programming Is the New Literacy*. Edutopia. https://www.edutopia.org/literacy-computer-programming

Resnick, M., Maloney, J., Monroy-Hernández, A., Rusk, N., Eastmond, E., Brennan, K., Millner, A., Rosenbaum, E., Silver, J., Silverman, B., & Kafai, Y. (2009). Scratch: Programming for everyone. *Communications of the ACM, 52*(11), 60–67. http://dx.doi.org/10.1145/1592761.1592779

Rose, S., Habgood, M. P. J., & Jay, T. (2020). Designing a Programming Game to Improve Children's Procedural Abstraction Skills in Scratch. *Journal of Educational Computing Research, 58*(7), 1372–1411. https://doi.org/10.1177/0735633120932871

Säljö, R. (2004). Learning and technologies, people and tools in co-ordinated activities. *International Journal of Educational Research, 41*(6), 489–494. https://doi.org/10.1016/j.ijer.2005.08.013

Shu, L., & Liu, M. (2019). Student engagement in game-based learning: A literature review from 2008 to 2018. *Journal of Educational Multimedia and Hypermedia, 28*(2), Article 2. https://doi.org/10.3102/1442816

Silander, P., Riikonen, S., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2022). Learning Computational Thinking in Phenomena-Based Co-creation Projects: Perspectives from Finland. In S.-C. Kong & H. Abelson (Eds.), *Computational Thinking Education in K–12: Artificial Intelligence Literacy and Physical Computing* (p. 0). The MIT Press. https://doi.org/10.7551/mitpress/13375.003.0008

Star, J. (2015). *When Not to Persevere Nuances Related to Perseverance in Mathematical Problem Solving*. https://www.semanticscholar.org/paper/When-Not-to-Persevere-Nuances-Related-to-in-Problem-Star/7885cccf2fa08a29438d55105ac404940d4d7fd9

Taylor, M. E., & Boyer, W. (2020). Play-Based Learning: Evidence-Based Research to Improve Children's Learning Experiences in the Kindergarten Classroom. *Early Childhood Education Journal, 48*(2), 127–133. https://doi.org/10.1007/s10643-019-00989-7

Vee, A. (2013). Understanding computer programming as a literacy. *Literacy in Composition Studies, 1*(2), 42–64. https://doi.org/10.21623/1.1.2.4

Wang, C., Shen, J., & Chao, J. (2021). Integrating Computational Thinking in STEM Education: A Literature Review. *International Journal of Science and Mathematics Education*. https://doi.org/10.1007/s10763-021-10227-5

Whitton, N. (2022*). Play and Learning in Adulthood: Reimagining Pedagogy and the Politics of Education.* Springer International Publishing. https://doi.org/10.1007/978-3-031-13975-8

Wing, J. (2006). Computational Thinking. *Communications of the ACM, 49*(3), 33–35.