Playful and Meaningful Learning of Programming. What does it Take to Integrate an App-Based Game Promoting Digital Mathematics into Early Childhood Education?

COLLECTION: DESIGN, LEARNING AND INNOVATION: FRAMEWORKS AND USES

RESEARCH

LINDA BARMAN

SUSANNE KJÄLLANDER

*Author affiliations can be found in the back matter of this article

ABSTRACT

This article shows conditions for how an educational digital tool can open doors to an increasingly playful world – and address some of the issues with introducing digital maths in early childhood education. Guided by a design-based research approach, the multimodal design of the educational app-based game DigiMat was iteratively created by a multidisciplinary team and introduced to teachers and children. In this study, we focused on transformative processes to illuminate conditions for meaningful *design for learning*, based on what teachers reported in interventions. In addition, we considered children's play with the app-based game, which elucidated the conditions for *design in learning*. We performed thematic analysis and applied the Learning Design Sequence model to illuminate notions from critical incidents with children and teachers. The findings indicate that, although children *re-design* and create their purpose whilst playing, beyond digital affordances, teachers needed an explicit alignment with the curriculum to integrate meaningful and guided play with the use of DigiMat. This study indicates that designers and innovators wishing to introduce playful apps into educational practice should consider how learning outcomes and playful activities resonate with educational practice. Based on our findings, we argue that digital educational tools should be designed and implemented collaboratively with teachers and children, in a didactic context where the goals of the curriculum are recognised.

CORRESPONDING AUTHOR:

Linda Barman

KTH Royal Institute of Technology, SE

lbarman@kth.se

KEYWORDS:

Early Childhood Education; programming; play; digital; app; multimodal; design for learning; meaningful; preschool; school; design-based research; learning

TO CITE THIS ARTICLE:

Barman, L., & Kjällander, S. (2022). Playful and Meaningful Learning of Programming. What does it Take to Integrate an App-Based Game Promoting Digital Mathematics into Early Childhood Education?. *Designs for Learning,* 14(1), 165–178. DOI: https://doi.org/10.16993/dfl.203

INTRODUCTION AND RELATED RESEARCH

The fostering of digital competence during education is a concern in many countries. In Sweden, the national strategy emphasises that all children and students, from preschool to higher education, should have the opportunity to develop such competence, arguing that: 'Digital competence is basically a democracy issue' (Ministry of Education and Research, 2017, p. 3). In response, the early childhood curriculum was revised to foster children's digital competence (SKOLFS 2018: 50). One way to achieve this national goal has been to focus on programming. In elementary school, the word 'programming' was written into the curriculum in 2018 (Swedish National Agency of Education Lgr 11, 2018; 2019). However, the implementation of activities where children develop digital competence has been far from a smooth process, and recent research shows a profession on shaky ground, where teachers are supposed to educate children to become digitally competent without being so themselves (Kjällander et al., 2021). To further progress in schools, the need to strengthen teachers' development of digital competence is recognised in research literature (Häkkinen et al., 2017). The current study considered the demands on teachers to ensure children's development of digital competence and programming, regardless the teachers' own formal training or digital literacy (cf. Kjällander et al., 2021; Erstad et al., 2021).

In addition to programming, computational (algorithmic) thinking has been introduced in K-12 curricula as a way to encompass a broader range of 21st century skills that are relevant for a digital society (Berge, 2017; Tedre & Denning, 2016). Examples from practice include computing unplugged with physical objects; the use of apps on tablets or programs on the computer; or tangible tools such as robots (Kjällander, Åkerfeldt & Petersen, 2016). Computational thinking (CT) is associated with, but not always captured by, the term digital competence, and CT in education is sometimes limited to the maths or technology syllabi (Berge, 2017). Algorithmic thinking and computation are part of frameworks describing computational thinking, but researchers and practitioners debate how to define the term, and descriptions relevant for K-12 education include concepts such as: problem formulation, data organisation and analysis, abstractions such as models and simulations, logical reasoning, decomposition, generalisation, patterns, representation and evaluation (Tedre & Denning, 2016). Central to the debate about introducing computational thinking in education has been that it supposedly helps children develop meta-cognitive and generic problem-solving skills. However the transfer of such skills to other domains does not seem to be supported empirically (ibid.). Computational thinking is a mental tool enabling the design of computations, and we agree with researchers claiming that the development of such abstract thinking takes time and involves learning a number of processes including algorithmic thinking and computation, as well as associated skills (e.g. Terdre & Denning, 2016). Based on a historical overview of CT, the authors argue that: 'We need to show our students what their programs are controlling before they can understand how to design programs that produce intended effects.' (Terdre & Denning, 2016 p. 126). Computational thinking thus involves understanding human behaviour and how to apply mathematics to address complex problems, and reducing it to programming as a coding procedure narrows the complex processes of digital competence needed for our way of living and learning (Terdre & Denning, 2016; Wing, 2006). Currently, it is the teachers' responsibility to ensure that all children apply digital tools in ways that stimulate their development and learning, which seems to be a challenging task for teachers who may lack the interest or the necessary digital competence themselves (Kjällander et al., 2021).

It is well known that some children have negative attitudes towards learning maths and, in a similar way, children's engagement in programming varies. Studies about efforts to address this issue suggest that active and playful learning can stimulate children's motivation to learn maths (Zosh et al., 2016). The Swedish preschool curriculum emphasises the combination of play and learning (Swedish National Agency for Education, 2018), suggesting that digital games designed for children to learn digital maths can be welcomed into the preschool setting. Researchers such as Manches, O'Malley and Benford (2010) argue that digital maths resources provide better affordances when these help children focus on maths, as they can simplify and uncover what is irrelevant. Previous research shows that young children are both interested in and can learn to program (Papadakis, Kalogiannakis & Zaranis, 2016). They can develop their ability to communicate and collaborate, as well as to analyse, organise and evaluate processes by engaging in programming activities (Kazakoff & Bers, 2014). Palmér (2017) showed how 3-year-olds learned to create and program robots, and that they were able to transfer their knowledge between different programming activities. In a study by Heikkilä and Mannila (2018), children developed their problem-solving skills when engaging creatively in programming. The research shows potential for integrating programming in early childhood education. However, there is a lack of programming apps where children can explore programming with modalities that offer formative feedback and support (Tärning 2018; Callaghan & Reich, 2021).

The current study was undertaken with the underpinning belief that children can be motivated to learn mathematics via playful activities (Zosh et al., 2016), and that digital resources are particularly useful during such play when the object of learning is digital maths.

We were inspired by several researchers suggesting that play is understood as a transformative design activity (Selander & Aamotsbakken 2009, Selander & Kress, 2010) – defined here as a:

> 'transformative design activity in which children are designing their own process by way of interpreting, negotiating and trying out different identities while making sense of affordances provided by the digital resource, within the frames of reference of their own experience and present interest.' (Kjällander & Moinian, 2014, p. 27).

In an effort to address several challenges with the introduction of programming and computational thinking for children in early childhood education, we conducted a design-based research project aiming to create an app-based game that helped children to play and learn digital maths. In this paper, we use the term digital maths when referring to the combination of computational thinking and mathematical knowledge that is useful for programming. The DigiMat app (https://digimat.tech), including the program, was designed to target and make an impact on children's development of computational thinking whilst learning programming. Digital maths represents the digitalisation of mathematics, in the form of automated and easy-to-understand computation of mathematical models. The focus of this paper is on the introduction of DigiMat in early childhood education.

The development of DigiMat was based on design principles that aimed to motivate children to learn digital mathematics, namely: *playfulness, meaningfulness and feedback*. By making use of computer games and physics simulation that unifies mathematics and programming, DigiMat was designed to take advantage of children's creativity and playfulness and thereby motivate them to engage in learning digital maths. The idea behind DigiMat was that, by learning a few basic algorithms, even young children could use the app to learn and carry out advanced programming and physics simulations. In addition – and in line with a research overview (Drigas, Kokkalia & Lytras, 2018) showing how digital resources are tools that can foster collaborative co-learning in preschool-aged children – the game narrative in DigiMat was developed to facilitate collaboration between children whilst they were playing and learning.

AIM AND RESEARCH QUESTIONS

The aim of this pilot study is to explore and discuss the conditions for integrating a digital app-based game aimed at playful learning of digital maths into early childhood education. Specifically, we explore the conditions for such a digital game to be meaningful for playful learning in early childhood education. Two specific questions guided our analysis:

- What conditions are needed for an app-based game in digital maths to be integrated into and made meaningful for teachers and children in early childhood education?
- What is required for an app-based game in digital maths to become playful learning in early childhood education?

DESIGNS FOR LEARNING

The theoretical framework used in this article fits within the frames of social semiotics (e.g. van Leeuwen, 2005) and multimodality (e.g. Kress, 2009) with a focal point at interaction, meaning creation and learning as sign-creating multimodal activities, something that is well described in the theoretical perspective *Designs for Learning* (Selander, 2017; Selander & Kress, 2010). Designs for Learning concern descriptions, interpretations and analyses of detailed aspects of modes such as symbols, layout, sound effects, gestures, speech, writing, images and colours (van Leeuwen, 2005; Kress, 2009). The perspective emphasises communication in situated activities and focuses on the transformation process, see Figure 1 (Selander, 2009; Selander & Kress, 2010), here represented by the digital interface where children and adults are elaborating and learn digital maths. Furthermore, this approach centres on representation of information and knowledge such as symbols, numbers, images, calculations, clicks and speech, with less consideration given to reception.

In the current study, theory was applied to contribute to the broader conversation regarding how digital resources may be useful for staging playful learning about digital maths in ways that are meaningful for teachers and children. DigiMat was designed to enable playful learning of digital maths but, as suggested by our theoretical perspective, both children and teachers transform knowledge representation and create meaning in ways that go beyond the app-based game. In that way, affordances are not just a quality of an object, or a physical environment that provides means of action. Rather, affordances are re-created in the interactive process when children and teachers re-design *for* and *in* learning. Learning is here viewed as a social sign-making activity and the result of a transformative engagement with something that leads to a transformation of semiotic or conceptual resources (Kress, 2009). Selander (2009) describes learning as: 'an increased ability to engage in a social domain in a meaningful way.' (Selander 2009, p. 25)

METHOD

This small-scale study explored conditions related to piloting DigiMat and was part of a larger project in which

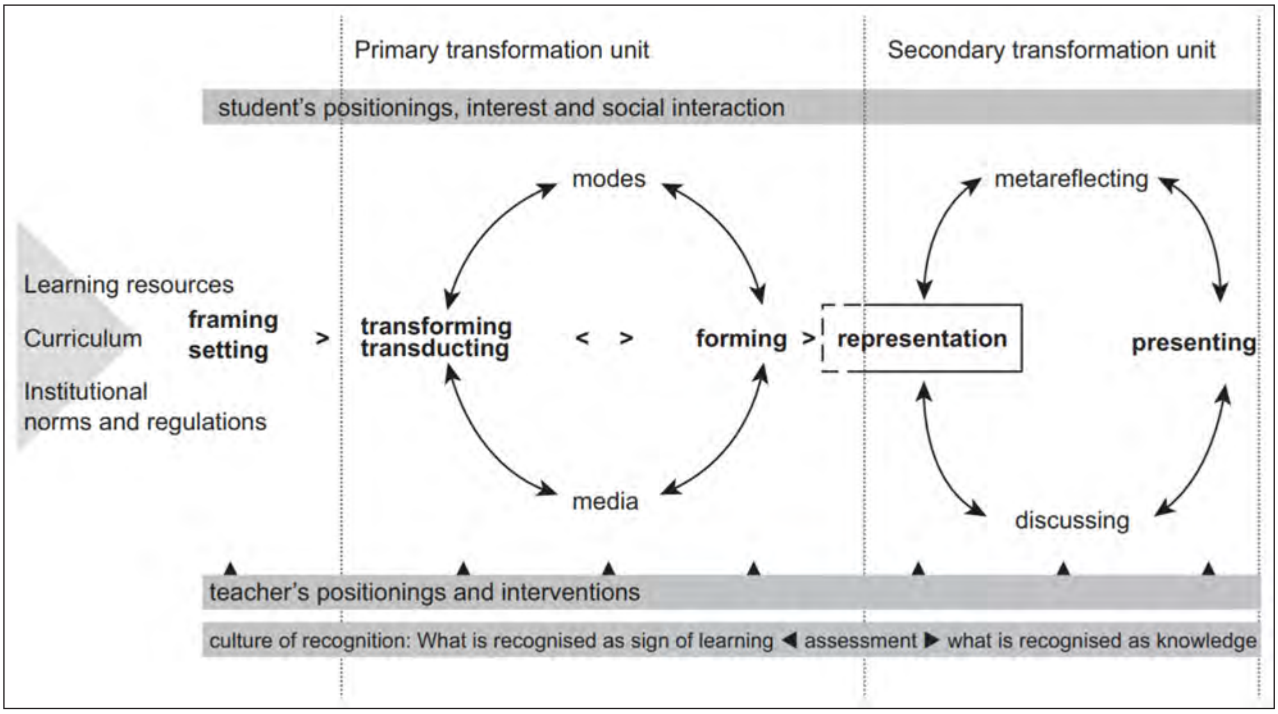

Figure 1 The theoretical model Learning Design Sequence, LDS (revised version of the model in Selander, 2008, p. 17; Revision by Selander and Boistrup, designed by Routledge).

a design-based research approach (DBR) (Anderson & Shattuck, 2012; McKenney & Reeves, 2018) was applied to develop and introduce DigiMat in formal education at different levels. The empirical materials included in this article were collected as part of the DBR project, and then purposefully chosen to address the current research aim. According to DBR methodology, the development of a technological artefact that is useful for learning should be conducted iteratively, based on multiple data sources gained through interventions performed in real education settings (Anderson & Shattuck, 2012). The rationale of DBR is to gain knowledge that is both applicable in the specific practice setting and able to inform others addressing similar issues (McKenney & Reeves, 2018). DBR emphasises the complexity when educational technology is developed, and that researchers and designers of technology need to engage with practitioners and consider the educational values embedded in different school contexts (Amiel & Reeves, 2008). The larger project was conducted in a multidisciplinary team of researchers from different disciplines,[1] and expertise in innovation, marketing and graphic design. The project included the development of the app-based game, taking in technological functions and narrative construction.

Applying DBR meant that tests and interventions with children and teachers were part of the iterative design process. As part of the larger project, but outside the scope of this paper (and therefore not reported here), the interventions informed the further development of the app, including the game narrative and the design principles. In this paper, we performed analysis to report findings regarding the introduction and integration of DigiMat in formal learning situations. Conducting tests and generating multiple data sources in accordance with DBR methodology allowed us to explore and gain transferable knowledge regarding *conditions* for introducing digital learning technology in formal education contexts beyond the specific case. Specifically, we applied theory to interpret the conditions for the app-based game to offer *playfulness* and *meaningful learning situations*. Thus, our study intends to inform researchers, innovators and practitioners who are looking to introduce technology that supports playful learning in early childhood education.

THE APP-BASED GAME DIGIMAT

DigiMat was based on mathematical interactive programming using Open Source technology (FEniCS framework) in a cloud-HPC web interface, aiming to provide easy access to educators and learners. DigiMat allows users to create simulations of processes in the physical world, based on the use of mathematics (algorithms). The app was tested so that users could access the game through a number of browsers and digital devices. The narrative called Ada's World was built around the mathematician Ada Lovelace, who is famous for introducing an algorithm for use in programming. Ada's World addresses learning about: distance, geometry, coordinate systems, and time stepping (since this study, several functions have been added). Users can shift between playing with symbols and text programming to make objects move and compile or create music strings. Using text programming whilst playing is optional (children did not have to program) and considered novel in Swedish early childhood education. Different narratives were tested and iteratively developed to include activities such as compilation of houses, helping Ada to organise a birthday party, dancing to music and creating melody snippets, and jumping up and down on a staircase. Multimodal functions were part of the game, such as sound when pressing symbols, music playing, and objects moving. The game was designed with graphical and colourful illustrations, and symbols to guide the user were added based on feedback from tests (for example a pointing hand).

DATA AND ANALYSIS

The empirical data in the current pilot study include on-site video recordings, photos and screen recordings, field notes from five different interventions (workshops), interview data from children and teachers, plus teacher's notes. Two interventions focused on children's play (participants: 5) and two workshops aimed at gaining teacher's perspective (participants: 7). The fifth workshop included both children (15) and teachers (2). In addition, during the initial app tests with children from early childhood education, two participants aged 12 and 14 gave feedback pertaining to the development of the app and the game (part of the larger DBR project) due to their experience of learning block programming at school and use of other digital games for learning maths. All five workshops were conducted between June 2019 and June 2021 at different sites, including two interventions in the authentic preschool setting. In Sweden, the vast majority of children spend considerable time in preschool; about 85% of children aged 1–5 years and 95% of children aged 4–5 years spend 15–50 hours per week in preschool (Swedish National Agency of Education, 2016). Therefore, the preschool setting was considered relevant for tests regarding how DigiMat might be introduced as a playful tool in early childhood education.

During the workshops, data collection was supported by an interview guide (Figure 2), naturally adjusted to the situation and whether the participant was a teacher or a pupil. The participants were also encouraged to use the tablets to show what they meant in the interview situation.

In addition, video recordings and field notes taken by several researchers provided information about what questions the teachers and the children had regarding the game, as well as how they approached the playful learning situation. The analysis was performed on purposefully selected material transcribed in short sequences, called critical incidents (Flanagan, 1954). The analysis of the critical incidents was guided by a selection of notions from the theoretical analytical model Learning Design Sequence (Selander, 2008). These notions are presented in italic in the excerpts/empirical examples. In this paper, we also report recurrent themes (Braun & Clarke, 2006) that shed light on the conditions for creating meaning and playful learning situations, in terms of staging playful and meaningful learning for children in early childhood education.

ETHICAL CONSIDERATIONS

The research process in the current project followed ethical guidelines (Swedish Research Council, 2017), and all participating children and their parents, as well as teachers, consented to participate after being informed orally and in writing. Pupils were asked for consent at each observation. If there was a 'no', their consent outweighed the 'yes' signed by their guardians.

Several ethical aspects were considered during this project, since the data collection involved children and early childhood education. For example, all data collection was aligned with policy documents, and educational activities were not staged by the researchers. Therefore, no physical or psychological risks were at stake for the research subjects. Activities added by the research team included video documentation carried out with respect for human dignity and human rights. We paid attention to whether participants expressed a sense that we were intruding on their privacy during observations. By discussing, asking and being responsive to the will of

Interview guide

Questions asked during the time educators and children played	*Questions asked after informants finished playing*
• Why do you do that? • What do you think's going to happen now? • What do you think this game is training?	• What do you think the game was about? • Was something fun? • Was something boring? • Was there anything that was hard to understand? • What did you think was math in the game? • Was there something you didn't know before, that you know now? • What did you think it was like to work together?

Figure 2 Interview guide.

the children and teachers, both verbally and physically we ensured that all participants were protected from risks that could have affected them negatively. Whilst observing children, we had a continuous dialogue with the present teacher to ensure that everyone felt confident with us. No observation had to be terminated due to any child's discomfort. Images presented in this paper were deidentified and all personal data on the participants was kept secure.

RESULT

The findings illustrate conditions for introducing DigiMat as a meaningful part of learning and play in early childhood education. The presentation starts with findings from four different interventions (critical incidents) exemplifying playfulness and meaningfulness in different learning situations, and lastly we present the identified conditions, based on analysis of recurrent themes in the data from workshops with teachers. The findings are organised as follows: 1) Meaning and play framed by a narrative; 2) Playful learning together; 3) Transformation of affordances becomes visible when teachers and children interact; 4) Feedback by reward; and 5) Explicit purpose and curriculum alignment.

MEANING AND PLAY FRAMED BY A NARRATIVE

In this empirical example, five children aged 4–14 were gathered at a university site together with the game development team, including experts in graph design and marketing as well as the researchers (Figure 3). The children were informed about the intentions behind the app and then asked to try out the functionalities in the first prototype.

At this initial test phase, the game intended to develop children's understanding of the number sequence of 1-2-4-8-16, illustrated by houses merging together into new sizes by programming or shaking the iPad, or using fingertips to merge them together. The game engaged the participants and they expressed that they thought it was both amusing and confusing or even 'chaotic'. Some children were happy to just play around, while others wanted to know why they should play. Recurrently, the discussions in the workshop concerned the purpose of the game. In this excerpt two children, denoted 'A' and 'B', the graphic designer, the marketing strategist and the researcher discuss how the game could be framed.

> A: *I get a little distressed by this. But they can't be put together, these houses!* B: *No, it's because they, the big, the biggest…* A: *The houses are disappearing. Oops…* A: *There are more of the bigger houses…* B: *If you [younger children] can only count to 16…* Graphic designer: *But I think that if it stops at 16, then it's a 16-house and after that: no more.* A+B: *Mmmm. OK. Well.* Marketing strategist: *But, then, should there not be some kind of little story or something about why you should do this, what is the point of it all?*
>
> The conversation continued about the need for a narrative, followed by a discussion about another game. B: *And you were given different amounts of money [depending on how well you succeed]. And then, you can buy new things.* Marketing strategist: *Oh, well, and then there was a point that you could buy something.*
>
> Researcher (to the children): *Do you have some thoughts about stories?* B: *I don't know what kind of story you can have for a house.* A: *It's hard to know what kind of story you can make with that.*

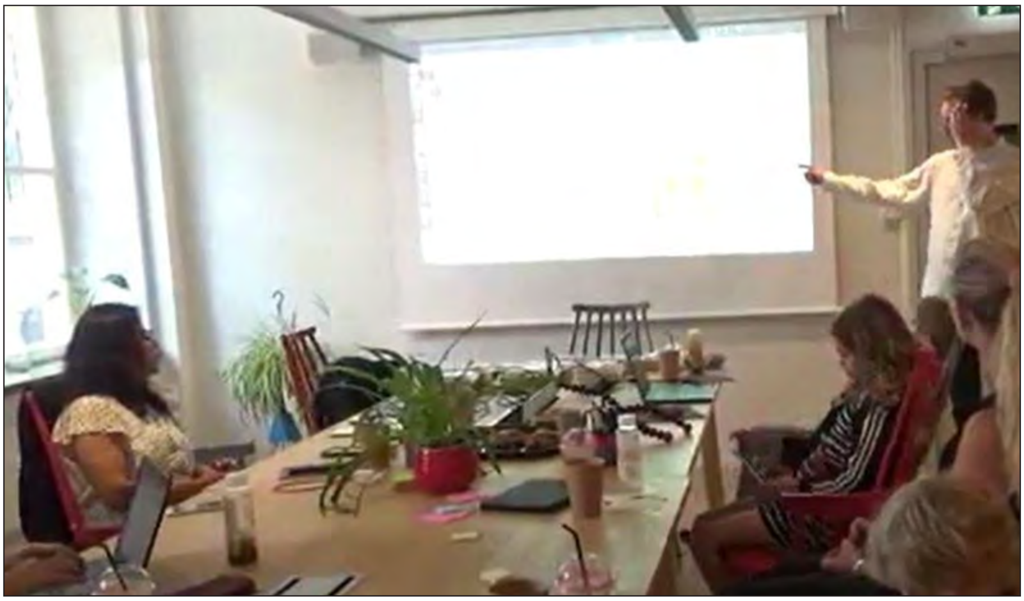

Figure 3 Pilot test with children – development of game narrative.

> *But maybe, as you said, there could be too many of you in that house and then you have to buy a new house and must get help to find it.* A: *...then it has a bit more meaning...*

The participants had different views about the app-based game: some of them were happy to play around for a while, whilst others thought it was chaotic and meaningless. The 'why' was seen as important, an aim or a cause to make the game worthwhile was perceived as a must. This could preferably be a narrative that attracts attention, interest or sympathy, but rewards were also discussed as a possible way to motivate children to engage.

This empirical example illustrates how difficult it is to understand and make meaning of, and even play with, an app when it is not situated in a context, i.e. where nothing is pronounced in the *setting* about how the *potential resource*s can be used, the *aim* of the app or what *institutional norms* may be at play. The app seemed chaotic and it was unclear how to *transform* and *form* maths knowledge when new maths *representations* (houses) seemed to develop regardless of participants' programming activities. The app needed to become its own *Learning Design Sequence*, with a *setting* and *transformation units* expressed in a narrative to make it meaningful and playful to children, and meaningful for teachers.

PLAYFUL LEARNING TOGETHER

In this empirical example, we met two children (aged 7) at one location and one other child (aged 6) participated remotely (Figure 4). They were connected via Zoom and they were all playing the same parts of the game, discussing with each other and the researcher during the session.

> Researcher: *What do you think about this game? Did it feel like a school assignment or could you do it at home?* A: *Fun. Yes (it felt like a school assignment).* B: *But it was more fun than a school assignment.* A: *Yes. A lot more fun.* A: *No (you would not do it at home). Yes (it is something you would do in school).* Researcher: *What is this game about?* A: *It's hard to explain. You should, like, add houses together... the red houses, you could call them, like... ones. They were kind of small, and they, and then... the blue ones... and they were, kind of like, in between... and then the threes, the yellow ones, they were bigger, so they become bigger and bigger the more you add them (together).* A: *If you count by size it (the yellow) is three.* Researcher: *OK. But why were there no threes?* A: *I don't know.* B: *Because there are no even numbers that together can become three.* A: *No.* B: *One plus one.* A: *First one, then two, then four, then eight.* B+A: *Then 16.* [Laughter]. B: *And then, if you go even further...* A+B: *32.* A+B: *64* A+B: *128.* A: *Ehm, hundred...* B: *136...* B: *No...* B: *236.*

> Researcher: *What did you think about working in pairs?* Both kids were smiling and holding both thumbs up, laughing. A: *Well, then (if working alone) it would have been harder to understand.* A: *Yes, we helped each other and such... Well, it was a lot easier.* Researcher: *Did you learn something that you didn't know before?* A: *No! Maybe... I must think.* Long silence while both kids are smiling. A+B: *Eeeeeeh.* A: *No.* B: No, I think I knew most of it already. A: Me too. A: But, it's like this, kids that are a little younger than us, and don't, like, know it all, they might learn about the houses and that.

Figure 4 Geometric sequences and engagement.

The children said that they enjoyed helping with the birthday preparations narrated in the game. They expressed an understanding that the game was about maths, and that it included geometric sequences (the binary number system: 1, 2, 4, 8, 16, 32, 64, 128, 256) although they did not know the term. Playing and engaging in learning digital maths seemed to be possible.

This example highlights that children may prefer to work cooperatively, not only because it is more fun (which was communicated by smiles and thumbs up), but also because it supports them in their learning. The *social interaction* between the children in the *extended digital interface*, where they interacted both on the screen with *media* and more physically around the screen with different *modes*, indicates that the app works for use in collaborative designs for learning. The digital game can be understood as *intervening* in the collaboration by means of multimodal *affordances* such as sounds, size, animations and words. The children's *interest* was obvious, and they liked the narrative and wanted to help the characters do specific tasks. It was also clear that the app needs a *framing* and to be *introduced* in a *setting* where *learning* is the main focus; the children need a school context to motivate them to play the app, as they considered it meaningful and fun as long as it is played within formal education. They expressed an understanding of digital maths while playing, when they *transformed* and *formed* their *representation* in terms of houses in different sizes. The children performed a *meta reflection* on the geometric sequence and their new knowledge – *signs of learning* – was visible when they listed the numbers, indicating that they can transfer their new knowledge from the game to another social interactive situation: an increased ability to engage in a new domain in a meaningful way (Selander, 2009).

TRANSFORMATION OF AFFORDANCES BECOMES VISIBLE WHEN TEACHERS AND CHILDREN INTERACT

In this empirical example we followed one group of 4–5 year-old preschool children (15) and their teachers remotely (due to Covid 19 restrictions) as they pilot tested the app together (Figure 5). The children were happy to play the app, and during a follow-up dialogue, the teacher reported:

> Teacher: *Things we* [educators] *were sceptical they* [preschool children] *would understand, they were totally into it, and some that we thought they would like, they didn't… they thought it was great to see the houses/monsters wrestling and hugging or playing tag to merge. The stairs with singles, tens, hundreds, thousands and tens of thousands they understood immediately. They were fully aware of what each house or monster represented*.

The analysis of how events played out during this intervention showed how the children were engaged in playing 'their' (designed) game. They made sense

Figure 5 Full control of representations.

of and created meaning from the app-based game, the narrative and the digital maths *differently to how the teachers thought they would*. The children enjoyed the play features of hugging, wrestling and playing tag. In addition, they interacted with more advanced mathematical representations than they were used to at this age: tens of hundreds are not commonly introduced to children of this age.

At this point in the app development, a narrative had *transformed* the game into something meaningful and engaging for the children to *interact* with. The narrative was appreciated by the children and caught their interest. The empirical material revealed that it was difficult for teachers to participate in workshops and to interact and discuss the shortcomings and the possibilities of DigiMat without the children present. Although the teachers were aware of their local *setting*, such as the child group and the curriculum, it was difficult to know how the app would be used, and *transformed*, by the children whilst playing, here interpreted as an expression of *design in learning* (Selander & Kress, 2010).

REWARDS AS FEEDBACK

In the following empirical example, two preschool children (C and D) were playing the game on a computer, while a teacher sat next to them (Figure 6). They did not take turns, instead they were both clicking and dragging items on the screen, one of the children was also using two fingers. They played around, laughing, pretending they were fish, monsters, airplanes and they were dancing while sitting on their chairs.

> C: *Go to the bank and see how much money we have got.* [A long verbal pause while playing the game]. C: *A coin! Playing again.* C: *Shall we have a look at how much money we've got?* D: *Money house!* C: *Only four!* B: *1, 2, 3, 4, 5.* C: *Ouch!* … D: *Wasn't this what we thought was hard before?* A: *Yes. That's because we didn't click on the money. A coin!*
>
> Teacher: *Do you think it is hard now?* C+D: *No. Nope.* D: *Now it's just good and fun.* D: [Turns around to the Zoom camera] *It's really good and FUN!*
>
> Researcher: *Did you get to know anything you didn't know before?* C: *Yes.* D: *Yes.* D: *That monsters could become really big monsters.* Researcher: *Why was it like that, do you think? Did it just happen by chance?* D: *It was us (who made it happen). We clicked on the monsters.* C: *If we didn't click on the monsters, we would DIIIEEE!*

At this point, a didactic design of rewards had been designed into the app. With this new design, children seemed to be more playful and *interested* in playing, and they also seemed to be more aware of their own agency. Digital maths, which is here represented as the merging of small items into bigger items (1-2-4-8-16) is not perceived as something that just happened, instead children were aware of why and how they had to merge houses together, which indicated that the children were starting to develop their computational thinking (Wing, 2006). They *transform* the houses, *form* multimodal *representations* and they *meta reflect* on their actions and learning, often framed by play in which they interpret, negotiate and try different identities while making sense of the game (Kjällander & Moinian, 2014).

EXPLICIT PURPOSE AND CURRICULUM ALIGNMENT

The game narrative also helped the teachers to design for playful learning of digital maths. The field notes

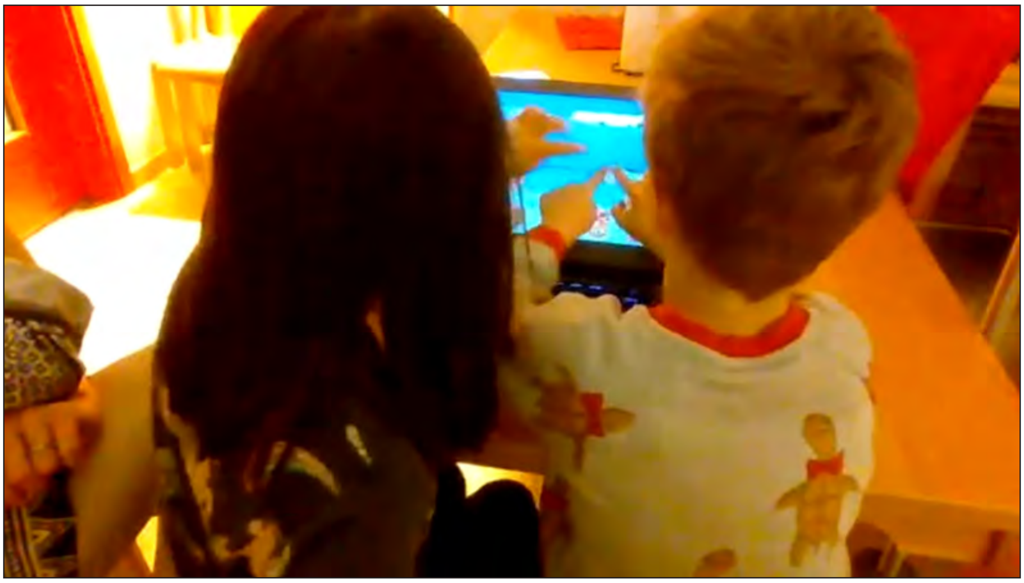

Figure 6 It was us who made it happen!

revealed that teachers needed to understand the aim and the narrative themselves, and that they believed the narrative was important for children to engage with DigiMat.

> Teacher: *We liked the video about Ada. Children of 3–5 want more narrative purpose and then they want to play. They don't want to be testing things, they want a fantasy world. They want to know how they can help Ada. Build the world around Ada. Their interest in this depends on the aim (of the game): to help Ada with the party.*

In the interview material with different teachers trying out the app-based game, some conditions were recurrently brought up. *Regulations*, such as accessibility, seemed to be a necessary condition, including that the app-based game should be free of cost and easy to access without any technological hassle. In addition, teachers needed to make sense of why and how to integrate the game into pedagogical situations characterised by playfulness and meaningful learning, hence how to design for learning with the use of the app-based game. *Representations* such as explicit learning outcomes and clear alignment with the curriculum were important conditions in the whole Learning Design Sequence. That way, the educators could make sense of the purpose of implementing DigiMat in their teaching practice, as illustrated by the response from one of the teachers:

> Teacher: *Show how this can be integrated in teaching. If you send an idea, a lesson plan, it could be remade into a programming activity.*

The teachers wanted to discuss and decide what *cultures of recognition* were at play while using the game in their teaching. The need for the game and narrative to have an explicit purpose, beyond what was introduced by the app itself, seemed to be more important to the teachers than the children. Whilst the children started playing, interacting and re-designing the game into their own play, as described by Selander (2008), the teachers wanted more instructions, guidance and clear purpose than during the workshops with the children.

DISCUSSION

The purpose of this article was to explore and discuss the conditions for making a digital app-based game aimed at creating playful learning of digital maths meaningful in an educational context. This small-scale study casts light on key characteristics for possible integration of digital tools in the physical classroom. The designed affordances of DigiMat were transformed by children while they were learning computational thinking via play. The app-based game was perceived as play by the children, who were keen on playing the game in an educational setting. The teachers in this study were positive about using DigiMat, as long as the learning outcomes aligned with the curriculum and the concepts used by the Department of Education, or other governing documents, and fitted into their local lesson plans. This study indicates the need for explicit and specific outcomes regarding what children can learn via an app-based game, and a clear purpose that frames the activities pedagogically and didactically. The teachers in this study seemed to want closer links between app content and early maths content. This implies that, even if technologically and economically accessible digital tools are available, teachers may not use these in their teaching if there is a lack of clear curriculum alignment.

THE CHALLENGING TASK OF DESIGNING A FUNCTIONAL APP

According to Moreno-Ger et al. (2008), creating a digital tool for educational purposes is not complicated – the challenge lies in making a tool that is both educational and entertaining. They highlight how many tools fail due to the sheer expense and time involved in development, testing and amendments. DigiMat was developed in close collaboration with both children and educators through a series of workshops, in which the user interface of the DigiMat prototype was tested and gradually revised until a more functional app was achieved. In addition, and as result of workshops with teachers, the integration of DigiMat into formal educational settings needed pedagogical framing with a clear connection to the curriculum and explicit learning outcomes.

Hirsh-Pasek et al. (2015) suggest four child-centric pillars for designing educational apps aimed at supporting learning in young children (0–8). These pillars align well with the affordances of DigiMat: *actively involved* (minds on), *sustained engagement* with the learning material by avoiding distractions, *meaningful learning* by connecting experiences to their lives, and *social interaction* including collaboration with others. Their research sought to bring learning science into the design of educational apps and described several pitfalls to avoid during the process, such as promoting root learning and including too many choices in the app (Pasek et al., 2015). The current study indicates that, even though an educational app is designed with these affordances in mind and the children seem to enjoy the app for playful learning, one condition for the app to be useful in practice is that teachers receive additional guidance on purpose and curriculum alignment.

CHILDREN COOPERATIVELY DESIGN PLAYFULNESS INTO THEIR LEARNING

In this study, although small-scale, we found that when children did not find the tasks in the app meaningful, they cooperatively found ways to make the game meaningful and playful in their own way. This transformation is possible due to designed affordances in the app – such as narrative voices, engaging music and the possibility to design dance moves. These affordances can be understood as playfully providing multimodal feedback, which is normally given to the children by the teacher. Here, feedback was provided by the app, something that is seldom the case for digital games in school (Tärning, et al., 2020; Callaghan & Reich, 2021). Similar findings regarding transformation of affordances are presented in related research (Ebbelind et al., 2021), where preschool children use and explore computational thinking and, guided by their own interest, transform tasks to become meaningful and playful. Furthermore, Ebbelind et al. (2021) state that programming can be a starting point for learning mathematics, which was one aim of the larger design-based research project of which the current study was part. If play is understood as transformative design, where children are designing their own process by way of making sense of affordances provided by the digital resource (Kjällander & Moinian, 2014), then programming can be understood as a playful way to teach computational thinking.

TEACHERS' AND STUDENTS' JOINT EXPLORATION IN THE FORMAL SETTING

The development of new digital resources or games for learning maths or programming in school has previously been criticised for lacking the involvement of teachers and/or children (Amiel & Reeves, 2008; Palmér, 2017). According to Ciampa (2016), who studied workshops as one method to develop digital tools, teachers must explore digital educational tools for themselves; it is not enough to be informed about them. We agree with both Ciampa (2016) and the critique regarding lack of involvement, and based on what this study indicates, the potential of apps may best be discovered in authentic environments with pupils and teachers together. In our pilot study we explored the use of one digital tool, in interaction with pupils and teachers who also interacted with each other in the extended digital interface. Moreover, interventions showed that the educators' anticipation of the children's play and engagement in learning was different from how it played out when workshops were held with children and teachers together. This implies that the design of digital tools intended for playful learning benefits from tests not only in the real educational settings, such as in preschool, but also in authentic pedagogical situations.

Formal education is obliged to educate for digital competence (Ministry of Education and Research, 2017), but the lack of instructions on how this should be put into practice challenges teachers (Kjällander et al., 2021; Häkkinen et al., 2017). If teachers cannot experience how children react when interacting with a learning tool, they may find it hard to further their design for playful learning in future situations where they are required to integrate digital tools in meaningful ways into everyday education. We argue that teachers may not discover the possibilities and constraints of app-based games until used by a group of children. Only then will new functionalities unfold and affordances be discovered in the interaction between children and teachers. Experiencing the app-based game in real-life school settings also enables a transformative process for teachers. In addition, the teachers in this study wanted to connect the 'what' to specific learning outcomes in the curriculum. Zosh and colleagues (2016) find support in previous research and discuss how guided play for children learning maths can be more effective than free play or direct instruction. The teachers in the present study expressed a need for more guidance on how to lead such guided play, if they were to introduce DigiMat. Earlier research also shows how activities involving digital tools need to be planned and well thought out to promote children's learning (Genlott & Grönlund, 2016).

ADEQUATE DIGITAL COMPETENCE: CUSTOMER COMPETENCE

One element of adequate digital competence, according to Swedish school policy (Ministry of Education and Research, 2017), is *customer competence*. A major research project on the implementation of digital resources in education in Sweden resulted in five phases of implementation (Grönlund, 2014), starting with: *purchase of software and hardware*. This was written into the Swedish national digitalisation strategy (Ministry of Education and Research, 2017). One of three milestones was that staff working with children and pupils should have sufficient competence to choose and apply appropriate digital tools in their teaching. (Ministry of Education and Research, 2017, goal 1.3). However, currently, teachers are seldom involved in making such purchasing decisions, although it is reasonable to believe that their insights into children's play, learning and development are needed in these matters. This study implies that digital tools should be tried out and explored by teachers and children together – in the classroom – to avoid the risk of meaningful design possibilities remaining invisible. We believe that it is important for teachers to reclaim their agency in choosing digital software and hardware that is useful in teaching. Traditionally, customer competence lies outside the learning design sequence's transformation units, included in what is part of 'the setting' in the model, since these resources have already been selected by IT staff who are seldom part of educational teams in local schools. If policy goals regarding schooling based on scientific results and proven experience are to be met, targeted investments in practice-based research on digital tools in schools are needed. Another requirement is new procedures, where scientific findings and reflected experience are implemented iteratively in didactic activities. Several researchers argue that new systems are needed to strengthen the development of a scientifically based education (Jackson & Cobb, 2013; Ryve, Hemmi & Kornhall, 2016). We believe that DigiMat and findings from this study can contribute to such a system.

CONCLUSIONS AND FINAL REMARKS

The present study set out to explore conditions for digital app-based games to become part of early childhood education, addressing demands on teachers to ensure children's development of digital competence and programming. Our findings imply that teachers should explore digital educational tools together with children in authentic educational settings to ensure meaningful and guided play. The findings strengthen what others have found, that there is potential for children to engage in programming and computational thinking, here referred to as digital maths, in preschool and school if activities are integrated in meaningful and playful ways. Our findings direct attention to the importance of involving teachers in the design processes for technology and in decisions on implementing digital resources, to ensure that these become useful – meaningful – in early childhood education.

Our study shows that app-based games need to be aligned with educational and institutional norms and the curriculum to be meaningful for teachers' practice. Furthermore, playfulness and meaningfulness are important principles in the design process, with the game being developed after each research iteration, as in the current study. Our findings imply that one of the most important factors for an app-based game's integration into early childhood education is the 'why'. In DigiMat, the aim was expressed via a narrative for children and teachers to engage with, whether it was about building or helping a character. Both parties explored the affordances of DigiMat in playful, collaborative and transformative processes that engaged them in computational thinking, thus showing the potential to learn digital maths and programming together – and develop their digital competence.

NOTE

1 Not all participating researchers are authors of this article.

ACKNOWLEDGEMENTS

We wish to thank the DigiMat Project Lead Associate Professor Johan Jansson and the app development team, and Malin Engquist for her involvement in data collection, as well as all teachers and children who participated in this project.

FUNDING INFORMATION

This study was sponsored by Vinnova 2019-01253 and The Department of Learning in Engineering Sciences at KTH.

COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR AFFILIATIONS

Linda Barman orcid.org/0000-0001-7148-3271
KTH Royal Institute of Technology, SE
Susanne Kjällander orcid.org/0000-0002-9333-8910
Stockholm University, SE

REFERENCES

Amiel, T., & **Reeves, T. C.** (2008). Design-Based Research and Educational Technology: Rethinking Technology and the Research Agenda. *Educational Technology & Society*, *11*(4), 29–40.

Anderson, T., & **Shattuck, J.** (2012). Design-based research: A decade of progress in education research? *Educational researcher*, *41*(1), 16–25. DOI: https://doi.org/10.3102/0013189X11428813

Berge, O. (2017). Rethinking Digital Literacy in Nordic School Curricula. *Nordic Journal of Digital Literacy*. *12*(1–2-2017), 5–7. DOI: https://doi.org/10.18261/issn.1891-943x-2017-01-02-01

Braun, V., & **Clarke, V.** (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. DOI: https://doi.org/10.1191/1478088706qp063oa

Callaghan, M. N., & **Reich, S. M.** (2021). Mobile app features that scaffold pre-school learning: Verbal feedback and leveling designs. *British Journal of Educational Technology*, *52*(2), 785–806. DOI: https://doi.org/10.1111/bjet.13055

Ciampa, K. (2016). Implementing a digital reading and writing workshop model for content literacy instruction in an urban elementary (K–8) school. *The Reading Teacher*, *70*(3), 295–306. DOI: https://doi.org/10.1002/trtr.1514

Drigas, A., Kokkalia, G., & **Lytras, M.** (2018). ICT and collaborative co-learning in preschool children who face memory difficulties. *Computers In Human Behavior* [serial online]. October 1, 2015; *51*(Part B), 645–651. DOI: https://doi.org/10.1016/j.chb.2015.01.019

Ebbelind, A., Kjällander, S., & **Palmér, H.** (2021). Matematik, digitalisering och programmering i förskolan. In: K.

Bråting, C. Kilhamn & L. Rolandsson (Eds.), *Programmering i skolmatematiken – möjligheter och utmaningar*. Lund: Studentlitteratur.

Erstad, O., Kjällander, S., & **Järvelä, S.** (2021). Facing the challenges of 'digital competence'. *Nordic Journal of Digital Literacy*, *16*(02), 77–87. DOI: https://doi.org/10.18261/issn.1891-943x-2021-02-04

Flanagan, J. C. (1954). The Critical Incident Technique. *Psychological Bulletin*. *51*(4), 327–359. DOI: https://doi.org/10.1037/h0061470

Genlott, A. A., & **Grönlund, Å.** (2016). Closing the gaps–Improving literacy and mathematics by ict-enhanced collaboration. *Computers & Education*, *99*, 68–80. DOI: https://doi.org/10.1016/j.compedu.2016.04.004

Grönlund, Å. (2014). *Att förändra skolan med teknik: "Bortom en dator per elev"*. Örebro universitet.

Heikkilä, M., & **Mannila, L.** (2018). Debugging in programming as a multimodal practice in early childhood education settings. *Multimodal Technologies and Interaction*, *2*(3), 42. DOI: https://doi.org/10.3390/mti2030042

Hirsh-Pasek, K., Zosh, J. M., Golinkoff, R. M., Gray, J. H., Robb, M. B., & **Kaufman, J.** (2015). Putting education in "educational" apps: Lessons from the science of learning. *Psychological Science in the Public Interest*, *16*(1), 3–34. DOI: https://doi.org/10.1177/1529100615569721

Häkkinen, P., Järvelä, S., Mäkitalo-Siegl, K., Ahonen, A., Näykki, P., & **Valtonen, T.** (2017). Preparing teacher-students for twenty-first-century learning practices (PREP 21): A framework for enhancing collaborative problem-solving and strategic learning skills. *Teachers and Teaching*, *23*(1), 25–41. DOI: https://doi.org/10.1080/13540602.2016.1203772

Jackson, K., & **Cobb, P.** (2013). Coordinating professional development across contexts and role groups: Teacher education and pedagogy. *Theory, policy and practice*, 80–99.

Kazakoff, E. R., & **Bers, M. U.** (2014). Put your robot in, put your robot out: Sequencing through programming robots in early childhood. *Journal of Educational Computing Research*, *50*(2), 553–573. DOI: https://doi.org/10.2190/EC.50.4.f

Kjällander, S., & **Moinian, F.** (2014). Digital Tablets and Applications in Preschool--Preschoolers' Creative Transformation of Didactic Design. *Designs for Learning*, *7*(1), 10–34. DOI: https://doi.org/10.2478/dfl-2014-0009

Kjällander, S., Åkerfeldt, A., & **Petersen, P.** (2016). *Översikt avseende forskning och projekt kring programmering i förskola och grundskola*. Stockholm: Swedish National Agency for Education.

Kjällander, S., Mannila, L., Åkerfeldt, A., & **Heintz, F.** (2021). Elementary Students' First Approach to Computational Thinking and Programming. *Education Sciences*, *11*(2), 80. DOI: https://doi.org/10.3390/educsci11020080

Kress, G. (2009). *Multimodality: A Social Semiotic Approach to Contemporary Communication*. London, UK: Routledge.

Manches, A., O'Malley, C., & **Benford, S.** (2010). The role of physical representations in solving number problems: A comparison of young children's use of physical and virtual materials. *Computers & Education*, *54*, 622—640. DOI: https://doi.org/10.1016/j.compedu.2009.09.023

McKenney, S., & **Reeves, T. C.** (2018). *Conducting educational design research*. Routledge. DOI: https://doi.org/10.4324/9781315105642

Ministry of Education and Research. (2017). *Nationell Digitaliseringsstrategi för Skolväsendet*; Bilaga till regeringsbeslut I, Volume 1; Stockholm, Sweden: Swedish Government.

Moreno-Ger, P., Burgos, D., Martínez-Ortiz, I., Sierra, J. L., & **Fernándes-Manjón, B.** (2008). Educational game design for online education. *Computers in Human Behaviour*, *24*(6), 2530–2540. DOI: https://doi.org/10.1016/j.chb.2008.03.012

Palmér, H. (2017). Programming in preschool – with a focus on learning mathematics. *International Research in Early Childhood Education*, *8*(1), 75–87.

Papadakis, S., Kalogiannakis, M., & **Zaranis, N.** (2016). Developing fundamental programming concepts and computational thinking with ScratchJr in preschool education: A case study. *International Journal Mobile Learning and Organisation*, *10*(3), 187–202. DOI: https://doi.org/10.1504/IJMLO.2016.077867

Ryve, A., Hemmi, K., & **Kornhall, P.** (2016). *Skola på vetenskaplig grund*. Stockholm: Natur & Kultur.

Selander, S. (2008). Designs for learning: A theoretical perspective. *Designs for Learning*, *1*(1), 4–22. DOI: https://doi.org/10.16993/dfl.5

Selander, S. (2009). Didaktisk Design. In S. Selander & E. Svärdemo-Åber (Eds.), *Didaktisk design i digital miljö—nya möjligheter för lärande*. Liber.

Selander, S. (2017). *Didaktiken Efter Vygotskij: Design för Lärande*. Stockholm, Sweden: Liber.

Selander, S., & **Aamotsbakken, B.** (2009). *Nordic identities in Transition: as reflected in pedagogic texts and cultural contexts*. Novus.

Selander, S., & **Kress, G.** (2010) *Design för Lärande: Ett Multimodalt Perspektiv*. Stockholm, Sweden: Norstedts Akademiska Förlag.

SKOLFS 2018:50. (2018). *Förordning om läroplan för förskolan*. Utfärdad den 23 augusti 2018. Stockholm: Skolverket.

Swedish National Agency for Education. (2016). https://www.skolverket.se/statistik-och-utvardering/nyhetsarkiv/nyheter-2013/allt-fler-barn-i-forskolan-1.193605. Accessed 31 May 2018.

Swedish National Agency for Education. (2018). *Curriculum for the Compulsory School, Preschool Class and the Leisure-time Centre*. Lgr 11. Stockholm: The National Agency for Education.

Swedish National Agency for Education. (2019). *Curriculum for the compulsory school, preschool class and school-age* *educare. (revised 2019)*. Stockholm: The National Agency for Education.

Swedish Research Council. (2017). Good Research Practice. https://www.vr.se/english/analysis/reports/our-reports/2017-08-31-good-research-practice.html. Accessed June 2019.

Tärning, B. (2018). *Design of teachable agents and feedback in educational software Focusing on low-performing students and students with low self-efficacy*. PhD thesis. Sweden: Lund University. DOI: https://doi.org/10.1080/10508406.2020.1770092

Tärning, B., Lee, Y. J., Andersson, R., Månsson, K., Gulz, A., & **Haake, M.** (2020). Assessing the black box of feedback neglect in a digital educational game for elementary school. *Journal of the Learning Sciences*, *29*(4–5), 511–549.

Tedre, M., & **Denning, P. J.** (2016). The long quest for computational thinking. In *Proceedings of the 16th Koli Calling international conference on computing education research* (pp. 120–129). DOI: https://doi.org/10.1145/2999541.2999542

van Leeuwen, T. (2005). Introducing semiotics. Routledge. DOI: https://doi.org/10.4324/9780203647028

Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, *49*, 33–35. DOI: https://doi.org/10.1145/1118178.1118215

Zosh, J. M., Hassinger-Das, B., Spiewak Toub, T., Hirsh-Pasek, K., & **Golinkoff, R.** (2016). Playing with Mathematics: How Play Supports Learning and the Common Core State Standards. *Journal of Mathematics Education at Teachers College*, *7*(1). DOI: https://doi.org/10.7916/jmetc.v7i1.787

TO CITE THIS ARTICLE:

Barman, L., & Kjällander, S. (2022). Playful and Meaningful Learning of Programming. What does it Take to Integrate an App-Based Game Promoting Digital Mathematics into Early Childhood Education? *Designs for Learning*, 14(1), 165–178. DOI: https://doi.org/10.16993/dfl.203

Submitted: 19 November 2021 **Accepted:** 27 September 2022 **Published:** 15 November 2022

Designs for Learning is a peer-reviewed open access journal published by Stockholm University Press.