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AUGMENTED REALITY IN MATHEMATICS: ENHANCING PUPILS' EVERYDAY SCHOOL LIVES

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Abstract: *This article presents findings from a study focused on using technology as a learning tool in education. Educational research on game-based learning argues that technology-based learning tools effectively enhance learning and memory. Augmented reality (AR) technology is attracting significant attention; its importance will continue to increase as new learning environments are exploited and new possibilities for promoting flexible and playful learning are revealed. This study investigated pupils' experiences with an AR application by comparing experiences and reflections from pupils who learned mathematics using the Wittario game-based learning application with pupils exposed to more traditional instructional methods. 72 pupils in 5th and 6th grade, divided into three different test groups, and 5 teachers were interviewed. The study revealed that the application provided more subject-oriented interactions, and pupils expressed a high level of motivation and peer affiliation when using the application. Our findings, therefore, reveal that using the application, especially when facilitating tasks that involve peer collaboration and interaction with a specter of features available, contributes to a positive learning environment. Also uncovered was that the teacher's presence and positioning of the activity in a pedagogical context are essential to this process.*

Keywords: *AR technology, learning, motivation, physical activity/movement, mathematics, gaming*

Introduction

The increased use of digital tools for both older students and young children in compulsory education 'has imposed new demands on teachers, who must be able to design new learning situations while relying on the growing supply of available digital resources' (Napal, Mendióroz-Lacambra and Peñalva, 2020, p. 1). Although digital tools are available, instruction is still in the hands of teachers; moreover, the learning process must be at the forefront of educational research on the use of such tools. International studies investigating how the integration of augmented reality (AR) technology into compulsory education impacts learning, motivation, and cognitive development provide new knowledge on how best to use this technology for learning. The current study investigated Norwegian 5th, and 6th-grade compulsory school pupils' experience using an AR application called Wittario, designed for learning in a mathematic lesson with fractions.

Virtual reality (VR) and AR systems combine the digital and real worlds by employing technological tools, such as 3D registration of virtual and real objects, and offer real-time interactions with virtual objects and simulated information layers in the physical environment (Azuma, 1997; Huang, Chen and Chou, 2016; Sanabria and Arámburo-Lizárraga, 2017). By integrating AR technology into mobile games, educators can increase learning through immersion and provide richer learning experiences (Schmitz, Specht and Klemke, 2012; Huang, Chen and Chou, 2016). Consequently, the learner's role in the 21st century has transitioned from knowledge receiver to knowledge transformer (Sanabria and Arámburo-Lizárraga, 2017), as pupils have become more active participants in learning processes due to the integration of technological tools in education (Huang, Chen and Chou, 2016).

While digital tools have gained access to educational spheres, physical activity has been overlooked (Skage, 2020), with pupils engaged in activities that do not require physical movement (Normand and Burji, 2020). Skage and Dyrstad (2016) found that introducing physical activity into theoretical learning processes created a more varied, meaningful, and active school day. Combined AR- and GPS-based games in education can reduce the passive element of learning and make activities more flexible and pupil-centered (Papanastasiou et al., 2019, Pellas et al., 2019), provided the game activities promote learning. An example is the Wittario app geolocation game, which, similar to games like PokémonGO, employs AR and the global positioning system (GPS) to combine physical activity and learning.

For this study, the learning perspective is anchored in a sociocultural tradition, viewing learning as a social process in which the individual depends on interactions with others to construct new knowledge. Thus, we elaborate on theories developed by Vygotsky (1978) to investigate the learning potential of a game-based learning tool that requires pupils to interact socially, guided by the following research question: How do pupils experience and reflect on their learning when they solve mathematical tasks using different learning approaches? This question is investigated by examining two groups of pupils' experiences with, and reflections on, solving mathematical tasks using the Wittario game-based learning app compared to one group of pupils who participated in more traditional mathematics instruction. Overall, we seek to understand the use of a game-based application in learning approaches from more conventional teaching via a basic use of AR to full use of AR in learning.

The Wittario application

The Wittario platform combines physical activity and in-app learning tasks using geolocation in GPS and AR. Tasks to be solved appear on a digital map of the players' surroundings based on GPS settings. A task appears as a flag on the map, and when the player approaches the flag's location, the task appears on the player's device (phone or tablet with an Internet connection). Tasks can be presented through various AR solutions, such as a trivia game with multiple choice answers, hierarchical/orderly placement tasks, sorting tasks, or tasks requiring more creative responses, such as submitting photos, videos, or free responses text via the app. The tasks assigned can be subject – or theme – relevant and can be chosen from a library or produced by educators using the app or working for the Wittario company. Each task is placed on a digital map in the app as determined by the teacher; sometimes, a distance must be walked before the next task appears. Therefore, the game can be played in the schoolyard, or the teacher can plan for a longer route in nearby recreational areas or facilitate learning in more urban scenarios. The game can be played individually or as a team. Teams can communicate through the app, with half of the team positioned indoors, controlling the digital map and guiding the other half, positioned outdoors, to the task's location (with players switching roles at some point). The game intends to facilitate pupils' physical activity and learning through solving the tasks.

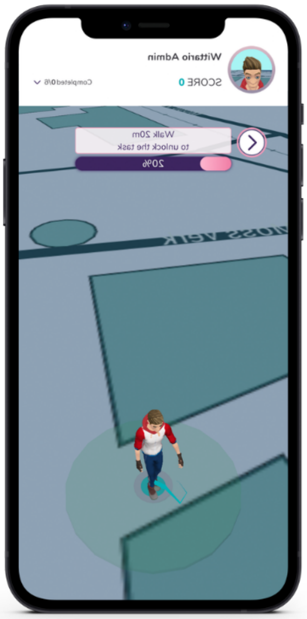

Figure 1: Example of Wittario GPS map

Figure 2: Example of AR task in Wittario

State of the art

Research has uncovered trends demonstrating that AR game-based tools have significant educational potential and can influence pupils' attendance, knowledge transfer, skill acquisition, hands-on digital experiences, and positive attitudes towards learning (Schmitz, Specht and Klemke, 2012; Shin *et al.*, 2012; Pellas *et al.*, 2019). Pellas *et al.* (2019) explained AR influences cognitive acceleration, self-management and engagement in practice-based activities. Furthermore, according to Videnovik *et al.* (2020), digital learning tools and AR games help students achieve beyond traditional learning goals and promote the development of problem-solving abilities, critical thinking and creativity, which are considered important 21st-century skills. Papanastasiou *et al.* (2019) argue how AR creates an immersed multimodal environment that can be enriched by multiple sensory features, that pupils can jointly explore interactive role-playing simulations in real-time; moreover, multiple learning environments can be created inside and outside the classroom, facilitating social learning and connections beyond institutional borders. Mobile devices offer additional functions, such as geolocation, videos, pictures and discussion forums. Pupils enjoy positive experiences with AR-based games that provide playful social activities in which they can enmesh themselves, forgetting they are engaged in learning (Videnovik *et al.*, 2020). Videnovik *et al.* (2020) proposed that technological game-based learning utilises pupils' energy and enthusiasm, while Papanastasiou *et al.* (2019) illustrated that AR improves pupils' learning and social, communication and creative skills.

To facilitate positive outcomes, teachers must link pedagogical approaches with the integration of games into educational practices (Videnovik *et al.*, 2020). These outcomes include enjoying positive experiences while playing games designed for learning (e.g. Lucht and Heidig, 2013; Hsieh and Chen, 2019; Videnovik *et al.*, 2020), but such activities can also increase learning, engagement and cognitive achievements (Shin *et al.*, 2012; Hsieh and Chen, 2019; Pellas *et al.*, 2019). However, studies have revealed that substantiating the positive effects of mobile game learning on pupils' knowledge acquisition is difficult, partly because quantitative data on game usage is lacking (Schmitz, Specht and Klemke, 2012). Indeed, discussions on the educational value of games provide little empirical evidence demonstrating this approach leads to better learning achievements (Schmitz, Specht and Klemke, 2012).

Theoretical background

A cognitive perspective of learning considers the individual's cognition, recognising that information is processed on a cognitive level, resulting in a change in cognition (see, for instance, Dewey, 1933 and Piaget, 1936,). Accordingly, individuals' ability to manage new knowledge primarily depends on their capacity, although some cognitivist scholars also consider the importance of modeling (for instance, Bandura, 1986). From a cognitivist tradition, using an AR app aims to add to and change an individual's existing knowledge, assuming intellectual growth within the learner. In contrast, behaviouristic theory views learning as occurring when a stimulus is applied to the individual to change existing behaviours, enhancing rewarded behaviours and reducing non-rewarding behaviours (see, for instance, Skinner, 1953). Thus learners play a more passive role in their education. In this article, we discuss the learning potential of the AR app from a sociocultural view, applying a Vygotskian (1978, 1987) perspective on learning. While digital tools that present problem-solving tasks can stimulate and engage learners, we have been specifically interested in how pupils reflect on interactions in the learning process.

Theory of learning

The work of Russian psychologist Lev Vygotsky (1896–1934) still has great potential for explaining learning processes (Faldet and Skrefsrud, 2020). He emphasised the interdependence of social and individual means of constructing knowledge, asserting that social processes shape children's cognition. According to Vygotsky, higher cognitive functions, such as logic memory, voluntary attention and concept formation, depend on social relations. Moreover, these functions are used by individuals to control their cognition, according to Vygotsky (1987). For example, to understand a new mathematical concept and its boundaries and content, the child experiences the concept in a social context and tests its meaning within social relations. This process shapes the child's cognition, and new learning is constructed. In this process, language is the mediating tool. Therefore, instructional methods that encourage pupils to test and use language with others in social contexts to activate concepts and collaboration will promote learning.

AR technology and learning

AR-based games enable learners to interact with digital displays, exploring compelling, imaginative and self-paced practical experiences that disrupt traditional systematic patterns for generating knowledge and skills (Sanabria and Arámburo-Lizárraga, 2017, p. 491). Reviews show that AR technology-based games facilitate pupils feeling 'personally embodied,' causing their actions to be intrinsically motivated and mentally preparing them for learning (Schmitz, Specht and Klemke, 2012; Pellas *et al.*, 2019). Further, the physical navigation aspect keeps students motivated and excited (Schmitz, Specht and Klemke, 2012; Pellas *et al.*, 2019). Additionally, studies show the collaborative group's size matters when using AR games through mobile phones (Melero, Hernández-Leo and Manatunga, 2015). Larger groups tend to enhance the game's social dimension while the technology becomes less visible. A study from Cascales-Martínez *et al.* (2016) substantiated the collaboration effect of using AR-based tools, stating that the feedback and exchange of knowledge established among pupils were vital, as they can solve problems together, which they found motivating. Silseth (2012) underpinned the social value, indicating the constitution of technological game-based learning resources comprises a collaborative meaning-making project; Silseth also highlighted the teacher's role as facilitator for pupils' adoption of learning in this manner.

According to Papanastasiou *et al.* (2019), AR technology tools enhance students' learning and memory, despite the challenges experienced, such as difficulties posed by GPS errors, camera or Internet technical problems, cognitive overload due to task complexity and teachers' inability to use the technology (Papanastasiou *et al.*, 2019). Other challenges result from participants without phones being more easily excluded from larger groups and levels of engagement in and focus on activities varying according to group size (Melero, Hernández-Leo and Manatunga, 2015).

Movement and learning

A review by Vetter *et al.* (2020) indicated evidence validating the learning benefits of incorporating physical activity into mathematics lessons is equivocal; however, it also indicated increased physical activity among schoolchildren is encouraged. Moreover, it is demonstrated that incorporating physical activity increases the engagement of low math performers, who seem to find the lessons more enjoyable (Vetter *et al.*, 2020). One study uncovered that physical activity among middle school pupils positively impacted their performance according to memory, with assessments performed shortly after the exercise showing the most significant benefits (Etnier *et al.*, 2020). Also, Kolle *et al.* (2019) revealed that increased physical activity positively impacted pupils' learning, noting the results depend on how physical activity is implemented into everyday school life and that teacher-led models seem to work best. Morris *et al.* (2019) referred to inconsistencies in the literature regarding the effect of physical activity on students' academic performance. They noted various studies investigating how the duration of activity impacted behaviours such as attention, task work and memory produced different results related to impacts on academic performance.

Despite the equivocal findings related to the positive impact of physical activity on academic performance, Vetter *et al.* (2020) concluded that active learning and physical activity are valuable for learners' health. Additionally, Sember *et al.* (2020) observed a small positive relationship between physical activity and academic performance, revealing that changes in academic performance are not caused solely by increased frequency and intensity of an activity.

Regardless of the inconsistent conclusions on pupils' academic performance related to physical activity, regular exposure to education outside the classroom positively impacts pupils' social relations and is associated with new peer affiliations (Bølling *et al.*, 2019). Additionally, activities outside the classroom are related to increased intrinsic motivation, which positively impacts pupils' autonomous motivation in school (Bølling *et al.*, 2018).

Research design

Study data were collected in fall 2020 from a convenience sample of three Eastern Norway schools selected from among a group of schools testing the Wittario app. The schools were asked to complete an AR game-based lesson with some pupils and a traditional lesson with others, after which we conducted interviews with pupils and teachers from one class from each school: one 5th grade and two 6th grade classes with pupils aged 10–12 years old. Seventy-two pupils and five teachers in total participated in the interviews.

School A teachers had some experience with the app from an earlier test run, but they had not used it as a working tool with the class participating in this study. Other than the test run, the participating class teacher had little to no experience using the app as a teaching tool prior the study. School B teachers had previous experience using the app, and one class teacher had collaborated with the Wittario company as a learning expert, developing subject tasks for the app (called collections), and had previously used the app as a learning tool with his class. Thus, the pupils from School B had prior experience with the app. School C's experience with the app was similar to that of School A; both pupils and teachers had participated in a test run, but the Wittario app had not been used as a working tool for teaching.

Although teachers can create tasks for the Wittario app, for this study, all classes used the same collection, created particularly for this study. The topic (fractions) was chosen from the curricula based on what teachers identified as relevant at this juncture in the school year to create a similar base for both interview questions and a knowledge test.

This investigation comprised two studies: A) the primary study involved group interviews with pupils and individual interviews with their teachers focusing on educational experiences in general and experiences with using the app, specifically; B) the secondary study involved a mathematical knowledge test on the selected topic and the pupils' tasks when using the app. The latter will be described under the heading *Knowledge test*. For both studies, the pupils were divided into three groups. Two groups were physically active in an AR-based learning session, each assigned one of two types of tasks we arranged for the collections: 1) problem-solving tasks requiring more discussion and 2) typical game-based multiple choice tasks. The intention was to examine possible differences in reflections and learning outcomes when some groups are given tasks requiring more discussion, as suggested by Vygotsky's theory of learning. The problem-solving and multiple choice groups used the app outside, remaining physically active while solving tasks in Wittario. The third (in-class) group worked with traditional classroom tasks and was not physically active. The rationale for this model was to open for discussion differences in outcomes between physically active and passive learners. Also, since we intended to discuss the learning potential of a game-based app from a sociocultural perspective, we differentiated between the app-testing groups by having different types of game tasks. Thus, the problem-solving groups were assigned tasks requiring more discussion and, therefore, more social interaction, while the multiple choice groups were assigned more typical game-based multiple choice questions.

Each class teacher was asked to place pupils in groups randomly, not differentiated by skill, gender or abilities/disabilities. Table 1 provides an overview of participants and groups according to the interviews. Analysis of the empirical data examined differences between the three groups (problem-solving, multiple choice and in-class) across the primary and secondary study. Interviews with teachers were analysed separately using the same categories. When investigating the pupils' responses, they often used and had limited explanations of their experiences. We, therefore, used the teachers' interviews to inform and shed light upon the discussed issues from their point of view. Both studies and the data analyses are described next.

Table 1: Overview of interviews

School	Interview	Type of interview	Participants	Tasks
A	1	Pupil group	4	Problem-solving
	2	Pupil group	5	Problem-solving
	3	Pupil group	6	Multiple choice
	4	Pupil group	5	In-class
	5	Pupil group	5	In-class
	6	Individual with teacher	1	-
	7	Individual with teacher	1	-
B	1	Pupil group	4	Problem-solving
	2	Pupil group	4	Problem-solving
	3	Pupil group	5	Multiple choice
	4	Pupil group	4	Multiple choice
	5	Pupil group	5	In-class
	6	Pupil group	4	In-class
	7	Individual with teacher	1	-
	8	Individual with teacher	1	-
C	1	Pupil group	4	Problem-solving
	2	Pupil group	4	Problem-solving
	3	Pupil group	4	Multiple choice
	4	Pupil group	4	Multiple choice
	5	Pupil group	5	In-class
	6	Individual with teacher	1	-

Interviews

We conducted group interviews with pupils after the mathematics lessons were completed, either using the Wittario app or through traditional instruction. Group interviews were conducted separately with problem-solving, multiple choice and in-house groups of 4–6 pupils each, corresponding to 16 group interviews: 5 with in-class groups, 6 with problem-solving groups and 5 with multiple choice groups. We also conducted five individual teacher interviews (see Table 1). Interviews were transcribed in participants' original language.

The developed categories are related to the rationale for the three test groups by the possible differences in reflections when pupils are presented with tasks requiring more discussions and physical activity. Deductive categories were thus developed in accordance with theory and the research question and included 'collaboration', 'motivation', 'physical activity', 'working methods' and 'learning'. According to Vygotsky (1987), the social level is primary and the individual psychological level is secondary. Internalization of concepts and understanding of phenomena is therefore seen as a result of activities on a social level, demanding interactions in 'collaboration' (Vygotsky, 1987). Thus, we wanted to investigate how the pupils and teachers reflected on the collaborative possibilities when using the application. The category 'motivation' was derived from prior findings, indicating that game elements in teaching engage and motivate learning and that outdoor activities are associated with increased intrinsic motivation (Schmitz, Specht and Klemke, 2012; Cascales-Martínez *et al.*, 2016; Bølling *et al.*, 2019). Using an application that requires outdoor activities, a key element in the conversation with the pupils and their teachers is 'physical activity'. Since physical activity has been overlooked while digital tools have gained access (Skage, 2020), and the Wittario application provides both dimensions, we were interested in possible reflections on using the app in an outdoor activity. Since the pupils used different 'working methods', we wanted to include their perspectives on 'learning', which is the rationale for including those categories. Two researchers read and coded all interviews and analysed them using the deductive categories through qualitative content analysis (Kuckartz, 2014). The pupils' interviews were analysed in two steps – first within each of the three groups, then between groups. Finally, the teacher interviews were analysed separately, following the same procedure.

Descriptive citations were then translated to English. Table 2 shows the distribution of statements from the pupils in the different analytical categories.

Table 2: Numbers of coding to categories

Group	Collaboration	Motivation	Physical activity	Working methods	Learning
Problem-solving	37	86	73	55	51
Multiple-choice	39	59	38	40	34
In-house	34	61	29	80	46

Knowledge test

The secondary study was a knowledge test, administered to the pupils twice: shortly after the AR game-based lesson (T1) and two weeks later (T2) in order to see if the learning outcomes changed between the groups over time. The pupils were faced with instrumental, problem-solving, and diagnostic tasks on the knowledge test, including 15 tasks about equal fractions, sorting spurious and real fractions, addition and subtraction with equal and different denominators, the extension of fractions and percentage and decimal numbers. The test was administered twice because, while Etnier et al. (2020) demonstrated that physical activity before exposure to a memory task can improve pupils' learning, they also found that moderately intense activities benefit memory performance most when learners are assessed shortly afterward.

Each correct answer received one point, and incorrect answers received no points. The answer had to be perfect; any mistakes resulted in zero points being assigned; thus, a partial understanding of the subject was not rewarded. Because of the small sample, only univariate analysis was appropriate, displaying a frequency distribution and averages for each pupil group. In the analysis, we first reviewed differences between the three groups at T1 and at T2 and then between T1 and T2. Differences between schools were rejected because of School B's previous experience with the app and the small sampling. Therefore, the final analysis differentiated between the groups as a whole. Even though we had a high response rate (74 of 75 pupils participated at T1 and 65 at T2), the total sample was small and not robust, so we used these findings to discuss the interview reflections.

Results and findings

The pupils were asked to reflect on their learning experiences, how they like to work with subjects, specifically mathematics, and how they believe they learn best. Pupils who participated in the AR game-based lesson were also asked about their experiences using the app. Teachers were asked to reflect on their teaching, working methods, how they believe pupils learn, and experiences with the app. Nonetheless, frequent similarities across the different groups, the reflections from the pupils revealed noteworthy differences in the analysis. Thus, we present the results, first by noting the similarities between groups, followed by the differences, both based on pupil and teacher interviews. Then the results of the knowledge tests are presented.

Similarities between test groups

Most pupils indicated they enjoy school, they like their teachers and prefer practical and aesthetic subjects. Appreciation for variation in activities was also commonly mentioned. The pupils identified similar issues related to physical activity and collaboration, which are illuminated in the following sections.

Pupils commonly expressed enthusiasm for going outside. However, the problem-solving group mentioned this aspect more often than the other groups (see table 2). The majority valued a break from the classroom, as many claimed they usually sit at their desks and get 'tired when sitting still and doing assignments' and 'from sitting still all the time', substantiating the need for breaks. Moreover, the pupils stated they grow tired from being inside but not if they can go outside sometimes. Some pupils believed that outdoor activity leads to more collaboration than working inside the classroom.

Further, some pupils claimed they 'think better' outside and learn more, partly due to lower noise levels outside and physical movement, which one girl described as 'when we can walk and complete assignments, then we think better'. However, a couple of pupils reported a preference for working on tasks inside, arguing that noise from cars and other pupils made focusing on tasks outside challenging.

Reflections on collaboration differed, but the majority said they enjoy collaborating with the app and find solving mathematical problems together helpful: 'If it happens that one knows more than the others, then he can teach the others'. Some pupils preferred working with others because they share their thought processes for solving assigned tasks: 'I like to collaborate: then we can ask how each other thinks'. Some pupils remarked that asking peers for help was easier than asking the teacher: 'Maybe if you need help, it is easier to ask a friend than your teacher'. However, others preferred working alone because focusing on tasks is easier: 'I prefer to work alone, so I don't joke around with my partner'. On regular mathematics tasks requiring mental arithmetic,[1] the pupils valued working as a group who could think and discuss the answers together to decide which was correct, letting the majority decide: '... and so we collaborate to see which answer could be right, and if several have the same answer, … then we use that answer because of the majority'.

Differences between test groups

The topic on which the pupils' reflections differed most was variations in learning activities. The groups generally agreed that they enjoyed variation in their activities. However, pupils in the problem-solving groups explained that the AR tasks made them forget that they were working on math problems. They elaborated on the specific type of problem-solving task: 'I learned much

[1] **Mental arithmetic** is the invaluable mathematics skill that involves completing calculations in one's head, without using tools, such as calculators, pen-and-paper or fingers.

more by demonstrating how you can calculate it – to take pictures, we had to find things to use, and then we learned to demonstrate it in the best way'. The pupils reflected on using the app features, such as pictures and videos, as possible ways to solve tasks using the app that allowed them to be creative.

One teacher observed the following concerning the problem-solving group and the assignments that required them to demonstrate their solutions: 'They were engaged and eager… they talked more about how they had reflected'. Building on this, a pupil stated: 'You become more friends with nature and surprised by all the things you can use – you become creative'. This illustrates the pupils experienced learning outside as a different experience.

Moreover, the problem-solving groups reported being motivated to learn by the app because it reminded them of other AR games (see table 2) and several pupils claimed that they remember more because of the app: 'I think we actually remember more than if we were inside with the teacher, because the teacher just shows us how we shall solve it, but with Wittario, we have to try to find a way by thinking for ourselves'. They reported how they enjoyed the tasks and remembered many of them. For example, one said, 'I think the photo tasks were fun because we had to show a half fraction, and then we took a stick, made a square, divided it in two, and we found some leaves to cover one half'. However, some problem-solving pupils described feeling stressed when the app lagged or the technique did not function. A teacher elaborated, explaining that some pupils did not like the map's layout in the app, so they were less enthusiastic about using it.

The pupils who worked on multiple choice tasks in the app said they enjoyed both multiple choice tasks and AR tasks. One said, 'They are the most fun tasks – you get to choose answers'. The virtual element was exciting, as one boy observed, 'It seemed real'. These pupils also seemed to enjoy the variation in learning activities. They liked the combination of completing a tedious task and a fun task at the same time: 'So when we mix different subjects or topics together, it can be fun, because then it is a boring thing mixed with a fun thing, and then everyone thinks it is fun in some way'. Some of these pupils stated that points were important for the overall experience with the app and that they liked the immediate feedback: 'Because when you get the score, you know it was the right answer, and then you think "Okay, then we can manage the next one as well", and you want to continue'. The pupils using the app also commented on the motivational value of points: '… it would be cool if you got points for money that you could use in a shop and maybe buy an avatar' and 'because then you have something to work for, a goal to reach'. They said they also became motivated by making progress in the app. One teacher explained that some pupils were more eager to advance in the app than to focus on the assignments. However, some of these pupils stated that points were not important because they learned from their mistakes, so answering incorrectly did not matter as much because they were still having fun. The pupils said that math became more interesting because of the virtual element, but they wished they had been allowed more attempts when they completed the assignments.

One group experienced challenges because one student primarily carried the phone and entered the answers, which led to some discussion. However, they still agreed that they had collaborated, although part of the group had resigned. A challenge with the AR tasks mentioned was that everybody could not access the screen simultaneously: '… like that AR, then it is a bit hard for everybody to touch the screen, hard to see, everybody is tight together'.

During the interviews, the in-class groups who experienced a more traditional classroom instructional approach often referred to other outdoor educational experiences involving physical activity and collaborative learning. They occurred often in other subjects such as science, social studies and history, during which they had many of the same physical activity experiences as the groups that used the app in terms of focus and motivation, expressing such thoughts as 'but it is more fun outside' and 'then you get air to the brain and think better'. These comments indicate that the pupils believed they needed to move throughout the school day and enjoyed being outside generating physical activity. The pupils were engaged and interested in talking about technical working methods and digital learning tools, especially programming games and Sphero, as they found programming challenging and requiring concentration. Such engagement may indicate the pupils find the activity fun and motivational, which they stated as possible factors in learning. In addition, they emphasised that rewards in the game are highly motivational. However, they questioned the actual learning outcomes from gaming in mathematics. Despite that, the pupils indicated they can learn from the app, which they had tried during the test run, by repeating things they already had learned: 'I remember things I learned from a long time ago; it comes back in my head, sort of', while statements such as 'I learned a lot, but got more from working in the textbook' conversely indicate less faith in the application as a teaching method. They did, however, express that the more traditional mathematics lesson resulted in more traditional teaching and less time for practice: 'The teacher used half the lesson to explain and instruct, but that's the way it has to be; we did not have much time to actually work on the tasks'.

Knowledge test

Table 3: Average result for test groups

Average results for test groups						
	Problem-solving		Multiple choice		In-class	
	*N**	Average result	*N**	Average result	*N**	Average results
T1	*N* = 27	5.63	*N* = 22	4.95	*N* = 25	4.28
T2	*N* = 24	5.71	*N* = 20	5.30	*N*= 23	4.96

**N* = number of participants.

The knowledge test included 15 one-point items, with a maximum score of 15. However, as seen in Table 3, no group exceeded 6 points, although most test questions were answered. The scores, therefore, reflect the correct answers given. If the test had been administered orally, the results might have been different, but in this case, the pupils were not allowed to ask the teacher for help or talk to anyone.

The differences between test groups (Table 3) were minor but still merit attention. For example, the problem-solving group had the highest scores at T1 and T2, while the in-class group had the lowest scores. Still, they did not differ significantly, considering the grading scale ranging from 0 to 15, and all groups averaged between 4.3 and 5.7, including both test points.

All groups showed improvement from T1 to T2, which may be because the same test was given both times and the pupils remembered the test items. However, the patterns between the groups at T1 and T2 are interesting. The multiple choice and in-class groups demonstrated approximately the same level of improvement from T1 to T2. Although the level of improvement was the smallest for the problem-solving group, those pupils still had the highest average test score at both T1 and T2.

Another factor to consider is that two groups had fewer people completing the test at T2 than at T1. The consequences would be insignificant in a large sample, but this most likely affected the averages in this case due to the relatively small groups. The knowledge test provides some indications of pupils' learning outcomes across groups and over time. Even though the sample was small and, thus, vulnerable, a pattern seemed to emerge (see Table 3) in which the problem-solving group had the highest learning outcome results while the in-class group had the lowest.

Discussion

This section discusses the pupils' learning processes when exposed to gamification that builds upon an app combining physical activity and multiple learning approaches. Its structure aligns with the theoretical perspectives, "theory of learning," "AR technology and learning," and "movement and learning." To understand the AR application's impact on pupils' learning processes and outcomes, the discussion primarily focuses on the results derived from the interviews with the pupils. The findings from the interviews with the teachers and the knowledge test results complement and support the arguments presented when pertinent.

Theory of learning

Despite differences in opinions about teamwork and collaboration, pupils commonly commented on the benefits of collaborative learning across the different groups. Our findings revealed that all pupils were involved during the game-based learning activity, for the most part, with the problem-solving group especially noting this. The pupils playing the game explicitly commented on the game providing opportunities for collaboration, a statement supported by their teachers based on the pupils' discussions after the game. The possibilities that lie in the AR game as an 'object-to-think-with' (Cascales-Martínez *et al.*, 2016) offer pupils an approach to problem-solving through discussion (see figure 3). According to the Vygotskian perspective, discussions on concepts in a social arena are essential for constructing new understandings. Although some pupils took the lead while playing the game, which may have left other pupils out, the majority felt they had learned from each other. Several pupils reported taking turns entering answers on the phone, indicating their sense of group affiliation (as argued from Bølling *et al.*, 2018). The fact that some pupils were in danger of being left out underscores the importance of the teacher acting as a facilitator and being present throughout the activity (cf. Kolle *et al.*, 2019). Therefore, addressing academic concepts in collaborative discussions has potential for individual learning (cf. Vygotsky, 1978). This may be why the learning outcomes for the game-playing pupils were somewhat better and why the problem-solving group, specifically in which pupils were forced to collaborate, earned higher scores on the knowledge test. In contrast, pupils from the in-class group did not have faith in the learning outcomes when using digital games and believed the more traditional instructional methods and working with the textbook provide better learning. Still, the knowledge test scores did not confirm their assumptions. However, they did indicate a desire to be exposed to more activities that enhance their school day, including being more physically active outside.

Figure 3: Example of collaboration using Wittario

AR technology and learning

According to Vygotsky (1978), communication is essential and must be at the forefront of any learning process. In our study, pupils from the problem-solving group highlighted the tasks that provoked creative collaboration, illuminating the benefits of using the app as a practical approach to subject matter and assignments. The various integrated functions of the app, such as the camera facilitated a playful and creative social arena for learning, utilising pupils' enthusiasm and energy (Papanastasiou *et al.*, 2019; Videnovik *et al.*, 2020) which enabled the problem-solving groups to solve tasks with tangible and creative solutions and visual responses using themselves, objects and materials they found outside, see figure 4 for an example.

The impact that tasks involving collaboration and finding practical solutions have on learning uncovered in this study aligns with Pellas *et al.* (2019). They unveiled that AR-based learning positively affects pupils when introduced to pupil-active assessments. The game-playing pupils in this study reported that they were motivated to learn because the app's similarities to other games they use for entertainment made them forget that they were engaged in a learning process; they were personally embodied in the learning process, which in the long run can increase their learning performance (Wei *et al.*, 2015; Huang, Chen and Chou, 2016; Papanastasiou *et al.*, 2019; Vasilevski and Birt, 2020).

An implied difference between the problem-solving and multiple choice groups was the basis for motivation. The multiple choice group enjoyed the immediate response they received and the combination of mixing a fun activity with what they called a 'boring' task. In contrast, the problem-solving group highlighted the fun of exploring the environment and surroundings and emerging in collaboration with their peers. The in-class group had input on learning while playing digital games on a more general level, addressing rewards as a motivational factor. Considering the knowledge test, the difference between the groups is interesting to note, pointing to the reward of completing the tasks as a motivational factor, as the problem-solving group, highly motivated to solve the tasks, earned the highest scores (see table 3).

Sanabria and Arámburo-Lizárraga (2017) stated that AR games facilitate social and creative learning, allowing students to be explorative and introduced to self-paced practical experiences. In addition to being suitable for social interactions and peer affiliations, teamwork supported pupils learning processes, as they had to discuss the subject to develop a joint answer (Cascales-Martínez *et al.*, 2016), supporting Vygotsky's theories of learning (cf. Vygotsky, 1978). However, one of the multiple choice groups experienced some challenges, partly because a few pupils took a lead role, excluding others from handling the phone. This underscores Melero, Hernández-Leo and Manatunga Melero (2015), who addressed challenges presented by group size, such as phone use being limited to one student at a time. Moreover, the multiple choice game did trigger pupils' instinct for competition and fast answers, compared to the problem-solving groups, which facilitated more creative solutions through videos and pictures, involving all pupils differently.

Figure 4: Example of pupils using camera to solve tasks in Wittario

Movement and learning

Our study shows that the game-playing pupils enjoyed being physically active outside the classroom and jointly agreed that breaks from indoor activities were cherished (see table 2). Moreover, the results show that playing the AR game, combined with being physically active, engaged the pupils and motivated them to learn, which is in line with Bølling et al. (2018). The combination of group work and physical activity was especially appreciated, underpinning Kolle et al. (2019) and Bølling et al. (2019) who emphasise the playfulness and social impact on learning of such a combination and the positive influence it has on pupils' social relations and new peer affiliations.

The results indicate that AR-based games that included physical activity were positive for pupils' physical well-being in both outdoor groups. Following Vetter et al. (2020), our findings revealed that the value of physical activities throughout the school day positively impacted pupils' engagement in learning activities, to which representatives from all test groups attested. We observed that engagement in activities unintentionally led pupils to emerge (Videnovik et al., 2020) in the learning process due to the playful physical approach to learning for the groups that used the app (see figure 5 for an illustration). According to Kolle et al. (2019), the pupils' positive statements related to physical breaks might impact their consciousness and concentration, positively affecting their academic performance. The in-class groups highlighted the need for breaks and the enjoyment of outdoor schooling as well when asked how their school day should be planned.

Finally, our findings illustrate that combining learning and physical activities outside the classroom helped pupils in the test groups, especially those who worked with problem-solving tasks, to remember what they had learned (table 3). In addition, they highlighted the impact of participating in an experience as opposed to simply completing an assignment at their desks. The pupils' experiences revealed the application's potential to motivate, engage and influence pupils to think positively about their learning processes, increasing their learning satisfaction and performance (Papanastasiou et al., 2019; Vasilevski and Birt, 2020).

Figure 5: Example of physical activity while playing the app

The results gave us some implications on the type of tasks presented in the application that benefit pupils' learning, supported by the implications from the knowledge test. Since the sample from the knowledge test was relatively small, it would be interesting to follow up with further studies when the application has been developed further and implemented within a regular practice. Furthermore, we see from our results that playing the game may contribute to inclusion for *all* pupils. For example, writing skill differences were not relevant during the game due to the app's variation for solving tasks, which underpins AR games' flexible approach to learning (Huang, Chen and Chou, 2016). This aligns with findings from Cascales-Martínez *et al.* (2016) that illustrated that AR technology is helpful for special needs students. These implications would be relevant issues to investigate further due to the increased use of games and digital tools in education.

Conclusion

Physical activity contributes to pupils' engagement and ability to reason abstractly and benefits their cognitive functions; moreover, AR-based games have been proven to enhance pupils' academic performance. Even though a mathematical test indicated that pupils working with problem solving tasks performed higher, the sample was too small to draw any final conclusions on the effect of the application. Interestingly, in this study, pupils described the use of the AR-based game app in a way that transformed mathematics from an academic subject to a practical subject. This study, therefore, proposes that combining learning and movement through an AR-based game app contributes positively to pupils academically, physically and socially. Furthermore, we found that the Wittario application is beneficial for the diversity of pupils that a class represents and contributes to peer affiliations and a positive learning environment if the full version of the app is used. However, the teacher must be present and position the use of games in a pedagogical context. Furthermore, the composition of groups and social environment must be considered, and the AR game must involve problem-solving tasks to reach its full potential as a learning tool.

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