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RESEARCH

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An embodied perspective on an augmented reality game in school: pupil's bodily experience toward learning

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Abstract

There has long been an increased focus on and investment in digital technology in schools to improve the quality of education. While digital tools have gained access to pedagogical spheres, physical activity has been overlooked, as pupils often engage in activities that require minimal bodily movement. In this article, we discuss pupils' experiences with learning through an augmented reality (AR)-based game application and explain how the application supports embodied learning. Digital tools, including gaming, can supplement traditional activities, motivate children to become physically active and enhance their learning experiences. Integrating technology and physical activity can create a more varied, meaningful, and dynamic school day, positively supporting pupils' learning processes. The AR game associated with this study facilitated physical activity and learning experiences through a mobile device application. The empirical material for the study includes interviews with pupils participating in an AR game in mathematics. The findings show that participating in an AR game promoted embodied learning and positively impacted pupils' motivation, engagement and learning processes. More specifically, AR facilitated learners' engagement in the learning process by fostering their active involvement through physical and social collaboration and by enhancing the pupils' joy of learning. Additionally, the pupils expressed that they enjoyed the application's variations and the experiences that followed working collaboratively with the tasks. Moreover, they commonly found the physical and collaborative components of the AR game exciting and academically motivating. Studies on AR games and technology focusing on the opportunities and pedagogical foundations for their use in education are relevant in these precarious times. Indeed, more knowledge is needed on the ways creative and flexible learning processes that transpire within a technological learning environment influence embodied learning, knowledge that is essential for designing teaching and learning in the technical future.

Keywords: Embodied learning, Augmented reality, Game-based learning, Physical activity

Introduction

Cognitive science has traditionally paid little attention to the outside world, viewing it to be of little theoretical interest, and those in the discipline have viewed the mind as an abstract information processor (Wilson, 2002). Historically, the human mind was considered the primary source of knowledge and learning, whereas the body was considered separate and its movements inferior to cognitive processes (Macrine & Fugate, 2022). However, in contrast to this classical view on gaining knowledge, in the 1960s Merleau-Ponty underscored the impact of the body on learning and argued the importance of the body's engagement with the world for gaining knowledge (Macrine & Fugate, 2022). Moreover, in recent decades, interest in viewing the body as a central component in the process of shaping the mind has increased (Wilson, 2002). Our understanding of human thinking and cognition favours an embodied view whereby cognition is grounded in sensory and motor activities (Macrine & Fugate, 2022).

The impact of motor or bodily activities was underpinned by Glenberg (2010), who argued that the body influences psychological processes and that human cognitions are affected by embodied interactions in physical environments. Furthermore, according to Dreyfus (Ward, 2018), understanding in all learning (subjects) is so demanding that the learning host's body and emotions become engaged. Dreyfus proposed that all perceptual and conceptual understanding is built on an embodied, embedded and affective foundation, meaning that our embodied and affective grip on a situation is not a dispensable feature of our relation to the world (Ward, 2018).

Embodied learning rests on the conception that body and mind do not function separately in learning processes. From an embodied learning perspective, individuals gain knowledge by exploring the world from where they stand and seeing details in relation to each other and to themselves in the world, perceiving the process as a form of holistic and synthesised acting, feeling and being-in-the-world rather than as a set of separate physical and mental qualities that bear no relation to each other (Stolz, 2015). Stolz (2015) further contended that an individual's engagement with the world does not merely involve cognitive or theoretical meaning but also can encompass emotional, practical and aesthetic interpretations. These varied meanings are united through humans' engagement with an act of intellectual synthesis, while the interrelated meanings give coherence to their worlds (Stolz, 2015, p. 485).

Today, learning and knowledge are influenced by the use and supply of digital tools in schools, both of which have increased in scope, which has led to new requirements, challenges and tasks for teachers (Napal et al., 2020). Some have questioned whether digital learning puts the fundamental embodiment and affective dimensions on the sidelines instead of in the spotlight. Indeed, the interest and point of departure of this paper is the role of embodied learning within education at a time when technology advancements often force children to work on digital tools individually at their desks. Therefore, this paper investigates primary school pupils' experiences with an augmented reality (AR)-based game application from an embodied learning perspective. AR technology combines digital value with real life using digital elements, such as images, video and three-dimensional effects, and offers interactions with virtual objects and simulations in a physical environment (Azuma, 1997; Huang et al., 2016; Sanabria & Arámburo-Lizárraga, 2017).

When teachers implement new digital tools, they must design a thorough teaching plan that ensures the digital device contributes to the benefit students receive from the lesson. Evidence has shown that the use of digital tools in education can facilitate more active participation in the learning process, through which students, to a greater extent, shape the knowledge they acquire themselves (Huang et al., 2016; Sanabria & Arámburo-Lizárraga, 2017). Nevertheless, such active participation is not necessarily aligned with physical activity; furthermore, traditional technology has been maligned as one of the causes of decreased physical activity and sedentary behaviour (Hansen & Sanders, 2011).

On the other hand, technology has provided an avenue through which children can play, exercise or be physically active; plus, several technologies have been created for digital games that encourage children to engage physically to play the game (Hansen & Sanders, 2011). Still, digital learning is often associated with learning that students access through a screen, one student to one screen (Johnson-Glenberg et al., 2014), which contradicts Merleau-Ponty's (1962) view of learning as physically and emotionally activated. The absence of embodied and emotional interactions can potentially leave pupils at a lower level of skill acquisition because bodily and emotional interactions are crucial to progressing to a higher level (Ward, 2018). Following Merleau-Ponty's view of learning, the digital domain, in its traditional form, will have clear boundaries, resulting in an isolated and fragmented learning exchange (Ward, 2018). Instead of being open to a questioning and active approach to learning, this form will be characterised by students who take a passive approach to finished products. Therefore, focus must be placed on the way courses are designed and on pedagogies that enable and scaffold a bodily, affective and interactive constitutive of understanding (Ward, 2018).

Hansen and Sanders (2011) emphasised the value of integrating technology and physical activity into the school, making learning more meaningful and increasing students' physical activity. Additionally, Skage and Dyrstad (2016) highlighted that introducing physical activity into theoretical learning processes creates a more varied, meaningful and active school day and, thus, positively affects students' physical and mental health and supports learning processes.

In a recent review, Flobakk-Sitter and Fossum (2023) noted that attention must be directed away from the technical aspect of using digital technology and focus more on the didactic and pedagogical use to promote learning. For example, Kosmas and Zaphiris (2018) called for research that explores the added value of embodied learning in game-based environments. Based on the increased use of digital tools in schools, their impact on learning, and the call for a pedagogical approach to digital technology, this study was designed to answer the following research question is: How do pupils experience learning through an AR-based game application, and how does the application support embodied learning? To present the answer to this question that we uncovered, we first describe the AR application. Second, we explain the literature review and account for our theoretical framework and methodology. In the remainder of the article, we present the results and discuss our analysis of the interview data.

The AR game application

AR technology allows learners to interact beyond the traditional context of mouse, keyboard and one-person/one-screen, which are not highly embodied interface tools (Johnson-Glenberg, 2018). On the other hand, AR technology can layer computer-generated enhancements and digital information on top of an existing reality or perceived physical world to make the experience more meaningful to interact with (Gill, 2018) and to give rise to the possibility of new kinds of educational learning processes (Bujak et al., 2013). Games with integrated AR technology can contribute to interactive and rich learning experiences and new relationships and connections (Schmitz et al., 2012). Moreover, the convergence of mobile devices and AR offers students an innovative experience during which they can learn and be physically active, which can improve students' learning performance, their positive attitudes and their engagement in the learning process (Nathan, 2021; Pellas et al., 2019).

However, the user perspective must be centred, and a broader understanding of the impact of AR systems on human activities is needed to release the full potential of AR games in learning (Li & Duh, 2013). Also needed to release AR games' full potential for learning is a present teacher who carefully introduces AR in a pedagogical context in which the composition of groups and the social environment is considered (Somby et al., 2022). Somby et al. (2022) underscored the importance of including educational tasks that require more engagement in the learning process to positively contribute to pupils' academic, physical, and social well-being.

The application used in this study's case was a game-based AR learning application called Wittario, which, like Pokémon GO, uses AR and the global positioning system (GPS) to combine physical activity and learning. The AR application offers various tasks on a map predetermined by the teacher. A task appears on the pupils' mobile devices when they have walked or run a certain distance. The application offers multiple ways to address the task and facilitates collaborative learning, such as through use of pictures, videos, multiple-choice items or written text. AR technology also possesses features that integrate the digital into the real world, such as by rearranging objects on the screen in size or order by moving the device. These immersive experiences allow pupils to interact with the learning content and to experience learning activities in environments that differ from the real world (Gill, 2018). The application provides the pupils with activities aligned with learning strategies that enable them to interact with the learning content through an AR application in a real-world context, including making movements when constructing mathematical knowledge and acquiring new schemas. The game played in this study also facilitated social interactions when played in groups.

Literature review and theoretical approach

In the following sections, we review research on technology-enhanced embodied learning, mainly focusing on AR applications' impact on learning from an embodied perspective. We follow this with a presentation of our theoretical perspectives on embodied learning, which serves as our analytical framework.

Technology-enhanced embodied learning

Developing and introducing designs for technology-enhanced embodied learning has been shown to benefit student learning and children's school experiences, improving academic encounters and making knowledge acquisition more interesting (Ioannou & Ioannou, 2020; Martli & Dincer, 2021). For example, immersive environments and bodily engagement positively impact vocabulary and grammar learning (Ferreira & Ribeiro, 2021; Suner & Roche, 2021; Thorne et al., 2021). Moreover, AR experiences have been proven advantageous to the learning of statistical reasoning, and students who participated in AR experiences reported a higher perception of engagement than those who did not participate (Conley et al., 2020).

A systematic review of mixed reality environments in K-12 education by Pellas et al. (2020) implicated mixed reality's potential to influence students' engagement, participation and embodied learning experiences for knowledge transfer. Furthermore, mixed reality features were reported to have impacted children's motivation and to have enhanced students' learning and memory (Bujak et al., 2013; Papanastasiou et al., 2019).

User mobility has been recognised as essential to affecting social dynamics during activities. Furthermore, devices that encourage bodily movements or activities can promote communication between users (Li & Duh, 2013, p. 125). Li and Duh (2013) argued that mobile AR games also can facilitate multiple users' bodily configurations, such as location and movement.

Recent studies have demonstrated that using AR in an educational environment helps students improve their 21st-century skills, such as communication, the ability to learn, and social practices (Ozyalcin & Avci, 2022). In addition, this technology offers students affective interactions and new ways of experiencing embodied physical and social interactions with the world (Dima, 2022; Sydorenko et al., 2021). Kumpulainen et al. (2023) tested the impact of augmented storying on children's ecological imagination. The results revealed affective, embodied and sensual intensities, highlighting AR's potential for affecting children's presence in and attention to the places they inhabit.

Embodied learning

Several understandings, theories and definitions claim that knowledge develops through activities that provide interactions between body and soul. Embodied learning and cognition is one such theoretical approach that has gained attention (Malinverni & Pares, 2014). The understanding and interest in embodied cognition have their philosophical roots in Merleau-Ponty, who emphasised the role of the body in learners' knowledge construction (Malinverni & Pares, 2014). Merleau-Ponty's thinking laid the foundation for investigating multiple directions regarding the connection between body and soul, a detailed explanation of which is beyond the scope of this article. Still, the viewpoints build on the understanding that psychological and cognitive processes in the brain are linked to bodily engagement in the learning process. From an embodied cognition perspective, knowledge synthesis is intimately tied to the reciprocal relationship between the body and the environment. Moreover, knowledge formation, integration and retrieval are contingent upon the interplay between individuals and their surroundings, pointing to the fundamental connection between cognition and the external world.

In this dynamic interaction, knowledge finds its grounding and situational context (Macrine & Fugate, 2022).

This article rests on the assumption that sensory devices activate neutrons that give a signal that affects the brain and, thus, the learning process (Jing & Ejgil, 2017). Further, Hung et al. (2014) observed that bodily movements, context and environment can positively contribute to the development of cognition and constructively impact learning and knowledge schema acquisition. For a lesson to be highly embodied, the learner must be physically moving, activating the motor neurons (Johnson-Glenberg, 2019). More neural pathways will be activated when adding motoric modality, which may strengthen the memory traces (Johnson-Glenberg, 2018).

According to Norman (1980), human cognition consists of the pure cognitive and regulatory systems. The regulatory system responds to the pure cognitive system and to the memory and language processes according to the human sensory stimulation received from the environment (Hung et al., 2014). On the other hand, an embodied approach suggests that human cognition is formed through the interaction of multiple information inputs, such as bodily states and environmental factors (Hung et al., 2014). The discourse on embodied learning reflects an awareness of bodily experiences as a source for constructing knowledge through corporeal activities related to physically sensing and being in both body and world (Freiler, 2008). Indeed, embodiment is 'the property of our engagement with the world that allows us to make it meaningful' (Dourish, 2001, p. 126).

Nevertheless, Skulmowski and Rey (2018) concluded in their review that the degree of bodily involvement cannot necessarily be used to indicate the degree to which a form of instruction is embodied. They, therefore, suggested that the extent to which bodily engagement is integrated with the learning tasks must be considered rather than merely considering bodily engagement as the primary dimension of embodied learning (Skulmowski & Rey, 2018). For example, movements related to learning mathematics should be relevant to the concept; in this study, pupils visualised fractions with their bodies or interacted with objects in the world by making fractions with sticks.

Scholarly focus is increasing on instructional methods that incorporate the body; these techniques create meaningful connections between physical movement and the principles and relationships in standard learning. This trend has been supported by new technologies that use bodily engagement as an input into digital environments (Nathan, 2021). According to an embodied cognition framework, almost all cognitive processes are influenced by an experimental approach to learning that includes bodily structures and physical states (Malinverni & Pares, 2014). Dourish (2001) used the term 'embodiment' to capture a sense of 'phenomenological presence', the way that a variety of interactive phenomena arise from engaged participation in the world (p. 115). Embodied accounts can be relevant to a phenomenological perception in understanding how technology mediates interpersonal communication, and AR-games can play this communicative role. Taking an embodied perspective on cognition relies on the view that cognitive processes are grounded in bodily interactions in real space and real time (Wilson, 2002). Further, as Dourish (2001) explained, embodiment is a common way to encounter physical and social reality in the everyday world.

Grounded and embodied theories challenge traditional views of cognition. The literature on grounded cognition accumulated at the beginning of 2000 (Barsalou, 2010).

Grounded theories propose that learning processes are grounded in sensory and motor systems rather than learning being isolated in abstractly amodal conceptual data structures (Pezzulo et al., 2013). Barsalou (2010) pointed out that grounded cognition theories indicate that cognition consists of multiple modules, including environment, stimulation, situated actions and body. 'From this perspective, the cognitive system utilizes the environment and the body as external informational structures that complement internal representations' (Barsalou, 2010, p. 717). Further, Pezzulo et al. (2013) underscored that a grounded perspective stresses learning as a dynamic of body–brain environment interactions where sensory, affective and motor processes are implemented during activities and, therefore, are intrinsic to cognition. Evidence has verified that the environment and the body play a central role in intelligence development (Barsalou, 2010) and that human cognition results from developmental, embodied interactions with physical environments (Johnson-Glenberg et al., 2014).

Taking a grounded cognition approach when studying cognition means that we consider that the development of knowledge and concepts is grounded in modalities and bodily states. Cognitive processes are understood as rooted in learners' bodily interactions with their physical and social environments and in the way motor and affective processes can support abstract thought (Pezzulo et al., 2013). Grounded cognition can be used as a methodological approach to study cognition as it explains 'grounded' from multiple perspectives, including the social and physical environment, bodily states and various modalities (Pezzulo et al., 2013).

Based on the understandings and views of knowledge development presented thus far, this study understands human meaning-making as a process connected to the social and physical environment in which individuals are situated, and we posit that bodily movements play a central role in human cognition. The analytical framework applied in this study rests on this understanding.

Methodology

Design

This study was designed to gain more knowledge about pupils' experiences with using an AR game for learning purposes from an embodied perspective in Norwegian elementary schools. Given the interest in how pupils experience and act in the world, this study was conducted following a phenomenological hermeneutic approach. A phenomenological hermeneutic approach implies recognising and emphasising participants' experiences. Through the analysis and the results, this paper emphasises discovery and unleashes meaning from the data by going in depth in the excerpts (Laverty, 2003). Considering the aim of the study, a qualitative research design was established using interviews as the method of inquiry because interview settings can allow researchers to gain insights into pupils' experiences, which are unknowledgeable, and expand intellectual power and knowledge about the inquiry by sharing and distributing knowledge among scholars (Brinkmann, 2014). The interviews followed a semi-structured design, using the knowledge-producing potential of dialogue and allowing leeway for following up on the participant's angles (Brinkmann, 2018). Since the participants were younger children, conducting face-to-face interviews with embodied presence was essential. This approach enabled interpersonal contact, context sensitivity and conversational flexibility (Brinkmann, 2018).

Procedure and participants

The data used in this study, obtained in the fall of 2020 as part of a larger project, were collected from three eastern Norway elementary schools (A, B and C) that had tested the AR application. Norwegian elementary schools focus on inclusive and active learning and are known for programmes that require students to spend significant time outdoors. The focus in recent years on learning outcomes, especially related to theoretical subjects, has prompted discussions on whether schools are too theory-driven, leading to a lack of practical learning. In addition, elementary schools in Norway have significantly invested in technology, such as purchasing individual iPads and computers for students. Therefore, we investigated the possibility of combining technology and learning in mathematics, a core subject, with the potential to learn outside, which leads to more practical learning. The eastern elementary schools were chosen because several schools in the area had started to explore the use of AR applications to create outdoor active learning environments to break up the traditional school day.

School A teachers gained some experience using the application by participating in a previous test run. However, they had not used the resource as a working tool in the class involved in this study. The teacher of the participating class, in particular, had limited to no experience using the application as a teaching tool prior to the intervention. School C had a similar experience. The students and teachers had taken part in a test run, but the application had not been employed as a working tool for teaching and learning purposes.

One of the teachers from School B collaborated with the software company as a learning expert, developing the application's subject tasks. This teacher had previously utilised the application as a learning tool in class. As a result, the students from School B had prior exposure to the application.

The 48 participants, who were in the 5th and 6th grades, were divided among 11 group interviews (see Table 1). A written consent form was distributed to the students and their guardians beforehand, and SIKT, 'Norwegian Agency for Shared Services in Education

Table 1 Overview of interviews

School	Interview	Participants	Tasks
A	1	4	Problem-solving
	2	5	Problem-solving
	3	6	Multiple-choice
B	1	4	Problem-solving
	2	4	Problem-solving
	3	5	Multiple-choice
	4	4	Multiple-choice
C	1	4	Problem-solving
	2	4	Problem-solving
	3	4	Multiple-choice
	4	4	Multiple-choice

and Research', reviewed the study's data plan. The local ethical board at our university was informed and consulted regarding methodological aspects involving children.

Two-thirds of the students in the participating classes took part in an AR game-based mathematics lesson, while the remaining students received a traditional lesson. We chose mathematics because it allowed for constructing two sets of tasks in the application: multiple-choice and problem-solving. We also considered lessons on fractions to have the potential to engage learners in creative work with natural elements to support learning. Following the activity, we interviewed pupils from one class in each school. Specifically, we interviewed one 5th grade class and two 6th grade classes comprising students aged 10 to 12. Because of the scope of this component of the research, for this article we retrieved the two samples that experienced the AR game. Each group was assigned a set of tasks in the AR application: (1) problem-solving tasks that required some degree of discussion or (2) typical game-based multiple-choice tasks. From an embodied perspective, the intention was to examine any existing differences in reflections and learning experiences. The interviews were conducted with students after they participated in the AR game session that served as a mathematics lesson. The participants were divided into two groups for the interviews: one with those who had experienced the application's problem-solving task and one for those who experienced the multiple-choice setup. As a result, 11 interviews were held—6 with problem-solving groups and 5 with multiple-choice groups—each consisting of 4–6 pupils (see Table 1). The interview recordings were transcribed in the participants' original language, and the authors translated the excerpts.

Data analysis

The theoretical framework and interview guide were used as a starting point for the analysis, and the empirical data were explicitly coded in accordance with bodily activity and the social and physical environment following the methodological approach to examining grounded cognition explained by Pezzulo et al. (2013). The analyses were conducted using NVivo, a qualitative coding software that facilitated the organisation, categorisation and exploration of the data, aligning with the methodological approach of grounded cognition outlined by Pezzulo et al. (2013). Deductive categories, thus, were developed following the theoretical framework and the research question and included 'physical interaction', 'social environment', 'physical environment', 'variation in methods (modalities)', 'challenges with the application', 'opportunities with the application' and 'functionality'. In line with the aim of the study and the theoretical framework, 'physical interaction', 'social environment', and 'physical environment' were selected for further analysis and discussion. The second coding helped to structure the results, inform the discussion, and prompt the division of the initial codes into child nodes. For example, the code 'physical environment' was divided into subcodes like 'temperature', 'ability to concentrate' and 'opportunities to move' (see Table 2).

Results

In this study, the pupils responded to questions about the way they experienced the AR application and the tasks given. In addition, questions about their learning processes were presented, facilitating a discussion to uncover the ways that bodily engagement and

Table 2 Child nodes

Bodily activity	Physical environment	Social environment
Attitudes towards activity	Concentration	Collaboration
Collaboration and activity	Different objects	Discussions or communication
Effects of activity	Learning	It is fun
Feelings of intensity	Opportunities to move	Opinions about learning
Learning related	Scenery	Opinions about social interactions or collaboration
Understanding of activity	Temperature and air	Support

the social and physical environment influenced their learning. This chapter is structured according to the three aspects of the embodied and grounded cognition framework, focusing on bodily activity and physical and social environment (see Table 3). The quote attributions identify the student participants with the label girl or boy, with the letter A, B or C in reference to the school, and with the abbreviation PS or MC, indicating the type of task they completed (problem-solving or multiple-choice).

Physical environment

The data collected from all groups revealed students' opinions regarding the experiences of being outside and engaging with different physical environments through the application. The most noteworthy expressions related to the physical environment revolved around learning and scenery. The problem-solving groups exhibited high engagement with the topic overall, while the multiple-choice groups were particularly captivated by the scenery and weather (refer to Table 4). However, no major differences were observed among the other groups, regardless of the assigned tasks (multiple-choice or problem-solving). Overall, participants appeared to agree that engaging in learning activities outdoors during the school day holds value (see Table 3).

A few pupils served as the exceptions, preferring to be inside to work in the book. Their expressions were primarily related to weather conditions, such as heavy rain

Table 3 Numbers of coding to categories

Tasks	Bodily activity	Physical environment	Social environment
Multiple-choice	26	29	10
Problem-solving	42	45	33

Table 4 Child nodes: Physical environment

Child nodes	Multiple-choice	Problem-solving
1: Concentration	1	0
2: Different objects	1	5
3: Learning	2	10
4: Opportunities to move	1	0
5: Scenery	8	9
6: Temperature and air	6	3

and cold temperatures. One pupil was ambivalent about being outside: ‘I think I might like being inside because I don’t really like going out and getting everything dirty’, but she also highlighted that ‘we get to be outside for a bit instead of just being inside for about two hours’ (Girl, A, PS). One learner said: ‘I think that being outdoors is really nice; I get to see and explore new things’, while another underscored the effect of the physical environment: ‘Being outside gives me lots of fresh air, and I get to stretch and collaborate on tasks’ (Boy, B, MC). Moreover, several pupils demonstrated an appreciation for the value of being outdoors by expressing an awareness of the physical environments, including two who said: ‘It is somehow better because I become… because inside I think it is quite warm and such, and outside it is maybe a little colder’ (Girl, A, MC) and ‘because somehow you get a lot more oxygen [outside], and the brain works better’ (Girl, P, MC). The experience with feeling the temperatures was mentioned by others as well: ‘It was cold’ (Girl, B, MC); ‘Yes, it was a bit cold’ (Boy, B, MC). When asked for their perception of the way working outdoors with the application affected their learning ability, one child responded, ‘I feel it is better to concentrate because I get fresh air in my head’ (Girl, B, MC), while another said, ‘After a while, it wasn’t much fun because you get freezing cold, and then it started to pour. And then you get thrown out of the game because the rain presses buttons and such’ (Girl, B, MC). Even though most pupils found playing the game outdoors fun and motivating, a few noted that they could concentrate better when doing mathematical tasks inside the classroom. For example, one participant observed the following:

> *I think it is more difficult to concentrate outside since it starts to get cold, and then there are a lot of cars and screaming, so it is not so easy to concentrate outside; whereas when we are inside, and then the teacher is inside, we are very quiet, so it is easier to concentrate. (Girl, C, MC)*

Several groups emphasised they found the variations to the traditional environment in which they usually learn to be motivating. One pupil described being able to remember a fraction after he had replicated it with natural materials and taken pictures of what he created (Boy, B, PS); another commented, ‘You could sort of use nature for that [visualising fractions], sort of shape things and stuff like that’ (Girl, A, PS). Another benefit of varying the learning environment was described by one of the learners this way: ‘If you use nature as a classroom, it [the classroom] becomes much bigger’ (Girl, C, MC).

Pupils from one school that used outdoor activities regularly as an arena for learning were more specific about their preference for learning outside. The pupils were aware of the physical environments in terms of fresh air and temperature combined with allowing them to be physically active, which they welcomed. ‘It was a lot of fun because you get fresh air, and you get to stretch a bit’ (Boy, B, MC). Others mentioned weather-related factors made them feel more focused and awake, which kept them from getting bored. ‘I just feel it’s better to focus because you get fresh air in your head. You can breathe’ (Boy, B, MC). A learner from a different school also mentioned the impact of external conditions, in this case referring to the effect of darkness on a classmate: ‘when she’s in class inside, she falls asleep if the light is off, while outside, if it’s dark, it’s… You feel a little freer in a way then’ (Girl, C, MC).

When asked which tasks they enjoyed, students praised the AR technology-based tasks for offering them alternative virtual environments. Pupils from the multiple-choice tasks group commented, 'It was like, it seemed, like, real. You can see from your phones; there is nothing there, and then you can look at your phones, and there is a lot there' (Boy, B, MC).

> *The tasks that are on the application, they make it so that... like AR, then you learn something if you, for example, make mistakes, but at the same time, it's been fun to do the task because it's like that in a way, almost like VR because you see that it's like 3D dimension, and you can go inside stuff like that. (Girl, C, MC)*

Based on the pupils' experiences, the AR game offers possibilities for bodily engagement with the surroundings and objects outside. Despite the existence of some ambivalence due to weather conditions, the findings show that learners valued the activity proposed by the application. However, based on the students' utterances, differences existed in bodily engagement and activities based on whether the student had been exposed to problem-solving or multiple-choice tasks.

Social environment

Despite some diverse experiences, the findings reveal few differences between the groups related to the possibility for social interaction, although the problem-solving groups stand out because they discussed the social experiences of using the application more (see Table 5).

Regardless of the experiences, the social environment inspired debates and different awarenesses. Overall, the pupils found the freedom of the outside environment valuable for group work since they could discuss possible solutions to their tasks while playing around. One youth highlighted as an advantage of being outside that she did not have to be quiet, nor did she need to be aware of other students' needs. Typically, students described the AR-game as engaging and highlighted the fun aspect of collaborating with their peers, a learning approach that several said they would prefer if given a choice. The ability to collaborate in groups was a frequent topic of interest when the pupils discussed the social environment. More explicitly, they appreciated collaborating to find the right solution to their tasks. 'You can help each other, and everyone can give different answers, and then everyone has to work towards the same answer' (Girl, A, PS). The pupils further acknowledged the advantages of working in a group when solving varied tasks, while several said they learned from each other while discussing and collaborated

Table 5 Child nodes: Social environment

	Multiple choice	Problem-solving
1: Collaboration	4	3
2: Discussions or communication	1	8
3: It is fun	0	4
4: Opinions about learning	2	3
5: Opinions about social interaction or collaboration	1	6
6: Support	0	5

when answering. ‘We discussed the different solutions and agreed on an answer’(Girl, A, PS). Another pupil noted, ‘I learned from my peers. When I did not know the answer, most likely somebody else knew it, and I learned from that’ (Boy, B, MC).

Additional thoughts about learning from each other’s opinions and knowledge were mentioned. ‘One may know something when the others do not know that thing, and then they can learn from each other’ (Boy, A, MC). ‘But then you also have different opinions’ (Girl, A, MC). ‘You also learn a little more [when collaborating]’ (Boy, B, MC). Furthermore, several learners described how they explain answers to their peers. ‘It’s like, if I have an answer, and then she asks how I came up with that, it’s really nice to explain’ (Girl, A, PS). ‘Eh, for me it is, they just ask me what the answer is because I’m seen as a bit smarter than the others’ (laughs) (Boy, A, PS). When asked why they thought they learned the tasks better when collaborating, one boy replied, ‘Hmmm, because, uh, they were more fun, and also, they’re not in the math book’ (Boy, A, PS). Another pupil shared the following experience, ‘Yes… because then if, for example, X has explained how X thought, I may also think the same way eventually, and then it will be much easier to remember and much more fun because then you feel that you can do it’ (Girl, C, PS). At the same time, one pupil highlighted the balance when asked about when he learned best, ‘It’s probably a bit of both. You have to practice with others, and you also have to concentrate a bit [individually] on something else’ (Boy, A, PS).

While most learners, when asked, said they found the social aspect of the activity to be fun and motivating, one group experienced some challenges and ended up dissolving. One group member stated that, to resolve the issue, ‘We just finished the game without the others’. One student found the activity confusing with all the groups involved, noting that ‘some are kidding around, and some aren’t’ (Girl, B, PS). The social environment additionally raised concerns about the game design and the application’s functionality. Although the game does enable collaboration, only one person at a time can handle the device and answer the tasks on the phone. ‘Like with AR [tasks], then it’s a bit difficult for everyone to touch the screen, difficult to see, for everyone is standing on top of each other’ (Boy, B, MC). Despite being limited to handling the device one at a time, this student still claimed that his group collaborated. ‘There was only one person who pushed [on the phone], but we collaborated on everything [else]’ (Boy, B, MC). Another pupil described the process their group followed to decide which answer to choose and explained how the group solved the issue of the handling of the device being limited to one person. ‘Well, it is like, if X holds the iPad, then everyone looks at the iPad, and X reads the task out. We all think until everyone finds an answer, and then we work together to determine which answer might be correct, and if several propose the same answer, such as 4.6, then we take that answer because it is the majority’ (Girl, C, MC). Nevertheless, the pupils were aware of the challenge of having just one device, and most groups except the one that dissolved said they managed to organise the collaboration within the group by taking turns using the phone to try the AR tasks and deliver the answers.

The findings related to social environment reveal some differences related to the tasks the pupils were given. The nature of the problem-solving tasks tends to enhance the collaboration and the interaction between the pupils. In contrast, multiple-choice tasks can make letting the one holding the phone go solo much easier. In summary, the AR game facilitated, to various degrees, depending on the task, collaboration opportunities and contributed to developing a social context for group learning.

Bodily activity, physical interaction

The premise for the application is that the pupils need to be physically active, either by walking or running through a predestined route, while solving the different tasks that appear on the phone. An overview of the coding related to the various groups is shown in Table 6, which illustrates the consensus of opinion regarding aspects of being physically active.

Besides a few comments on weather conditions (like one from a participant indicating she did not like to be outside when it was raining), the pupils' feedback showed that they found experiences with bodily activity valuable. Overall, the problem-solving groups, except school C, paid more attention to the physical part of the activity. Pupils from school C talked less about their physical experiences, regardless of whether they belonged to the PS or MC task group. To communicate about their experiences with the ability to use their body more than they usually can in a traditional classroom setting, students uttered expressions like 'It was actually quite fun' (Boy, A, PS), 'It was fine' (Boy, A, MC), 'You get very tired of sitting still all the time' (Girl, A, MC) and 'You become much more fit' (Girl, A, MC).

The findings showed that one participating learner believed she may be able to concentrate better outside: 'I become… it's kind of better because I… because inside I think it's quite warm and stuff, and outdoors it's maybe a little colder. Also, maybe I concentrate better' (Girl, A, MC). On the contrary, other pupils did not fancy bodily movement when doing mathematics.

> *I think it's more difficult to concentrate outside since then it starts to get cold, and then there's a lot of cars and screaming, so it's not so easy to concentrate outside; whereas when we're inside, … the teacher is inside, so we are very quiet, so it is easier to concentrate. (Girl, B, PS)*

One pupil proclaimed that she was able to think more clearly while moving outside: 'Then you can walk while doing tasks, [and] then you think better' (Girl, A, MC). Additionally, students enjoyed the variation in the tasks that facilitated bodily movement as a group by requiring students to use natural materials to visualise a mathematical answer and take a photograph of it. 'I learned much better from demonstrating how you could calculate. With the fact that you were supposed to take pictures, you had to find things

Table 6 Child nodes: Bodily activity

Child nodes	Multiple-choice	Problem-solving
1: Attitudes towards activity	12	15
2: Collaboration and activity	1	1
3: Effects of activity	4	7
4: Feelings of intensity	6	5
5: Learning related	9	12
6: Understanding of terms	0	1

to do like that, and you learned to demonstrate it as best as possible' (Boy, A, PS). 'I mean, you become a little more friend with nature and I am a little surprised at all the things you can use' (Girl, A, PS). Alternatively, they can act out something and respond to the task with a movie clip on the phone. The students were asked how the pace and intensity of their bodily activity influenced their ability to solve the tasks; they responded that they had no particular affect. Examples of comments about the intensity of physical activity were contradicting: 'No, not that tired at all. You feel fatigued by sitting entirely still and doing tasks, and you get very tired of sitting still all the time' (Girl, A, MC) versus 'If we somehow go out into the forest far away, I get pretty tired in my legs' (Boy, A, MC). One participant (Boy, B, PS) uttered that solving the task was more stressful when they were exhausted, but when asked whether their learning was impacted, they answered: 'No, not really' (Boy, B, PS), 'No' (Girl, B, PS) and 'It might just make us have some more wrong answers, especially if we are short of breath' (Boy, B, PS).

Overall, the pupils' descriptions of their experiences showed that they were aware of the physical and social environment when performing activities. Although few pupils commented specifically on the physical environment or on being outside, they seemed to generally recognise the variation in their school day and observed that being outside for a change was nice, indicating that varying students' learning activities and physical environments positively impact their motivation and spirit during knowledge acquisition.

Discussion

This section presents a discussion on the ways the pupils experienced learning through an AR-based game application that combined physical activity and multiple learning approaches, as well as on the ways AR facilitated embodied learning. The discussion's structure aligns with the research question, first describing the pupils' experiences with the application and then addressing the way AR supports embodied learning based on an embodied framework focusing on the physical and social environments and bodily activities.

Pupils' Experiences

Several findings associated with this study echoed those of other studies on AR technology in the literature. An example is technology-enhanced embodied learning, in this case, adding AR application content to make learning more interesting and motivating for the pupils (Martli & Dincer, 2021; Papanastasiou et al., 2019). Additionally, the findings revealed that the pupils appreciated the break and the variations in the lessons leading to engagement in the learning activity, underscoring Conley et al. (2020), who reported higher engagement among students who engaged in AR.

Based on the findings, the AR application offers children embodied opportunities for variation throughout their school day and is a possible approach to enhancing pupils' learning experiences. Outdoor learning-based activities especially were appreciated. The outdoor context offers a rich tapestry for contextualised learning. As the pupils solved mathematical problems using the AR application, they applied the same concepts to real-world scenarios found in nature. This contextualisation can enhance the relevance of the learning material, making it more meaningful and applicable to students' lives. Motivation is an essential driver for the learning process. The AR-based game application used in this study leveraged this intrinsic motivation, seamlessly integrating technology and the outdoors. The problem-solving tasks became not just academic exercises but also exciting challenges the pupils were eager to tackle in the dynamic, open-air environment. Using learning applications with AR can, therefore, create rewarding activities that inspire students to learn and enhance children's social and physical activity and participation in their learning process, as evidenced by recent research that found that AR improves 21st-century skills and enhances students' social interactions and skills (Dima, 2022; Ozyalcin & Avci, 2022; Sydorenko et al., 2021). Freiler (2008) recognised bodily experiences when constructing knowledge, which the pupils mirrored in this study by highlighting physical activity as a welcoming break from what they experience as sedentary activities in the classroom. The tasks given in the application contribute to the social environment and encourage bodily movements that promote communication, which Pezzulo et al. (2013) and (Li & Wang, 2022) highlighted as an essential characteristic of embodied learning. The outdoor setting also naturally promotes collaboration among students. As they worked on problem-solving tasks together, the AR application catalysed collaborative learning experiences. The interactive nature of the technology encouraged peer-to-peer discussions and knowledge sharing, fostering a sense of camaraderie and collective achievement. Specifically, the problem-solving tasks enhanced the groups' social interactions, underpinning Li and Duh (2013), who emphasised AR`s ability to enhance opportunities for generating social experiences.

Nevertheless, this study could not easily identify the actual impact of movement and the environment on learning because some of the statements made about the way the pupils experienced the AR game were inconclusive. Still, the pupils' expressions indicated that the game impacted the way they experienced their learning situations. Furthermore, the pupils explained that those in their social environment usually cooperated to arrive at solutions to problems: 'Everyone has to work towards the same answer' (Girl, A, PS). At the same time, since they only had access to one phone, someone could always take charge and exclude others. The experiences varied among the groups, all groups allowed for one student to take the lead, despite the task at hand. To eliminate the risk of solo play when the aim is to create a social environment, the game should be set up with fewer multiple-choice tasks and, instead, emphasise problem-solving activities or tasks that generate collaboration to solve the given task. Thus, following Flobakk-Sitter and Fossum (2023), the selection of tasks should be carefully designed and founded on pedagogical and didactic thinking to benefit from the application's potential for establishing learning in a social context.

The findings revealed the application's potential for promoting pupils' ability to experience the physical environment and to activate their sensory modalities, aligned with Pezzulo et al. (2013), who considered knowledge development grounded in bodily states and modalities. These results also support the findings reported by Dima (2022), who asserted that AR offers students affective interactions. In addition, pupils in this study reported an awareness of both the weather, either cold or rainy, and the physical surroundings, consistent with Kumpulainen et al. (2023), who found that AR revealed sensual intensities affecting children's presence in and attention to the world. For some tasks, pupils were encouraged to use natural elements or their bodies to form an answer or to look for something to photograph, which better integrates the given task with the objects of learning and the principles of embodied learning (Skulmowski & Rey, 2018). Following Pezzulo et al. (2013), who recognised learning as a dynamic body–brain environment interaction during which the sensory processes are implemented into the activity, the findings show that this AR application facilitated embodied learning. The pupils experienced the physical environment through their senses when they were simultaneously physically active and social in collaborating to create solutions to the tasks. Pezzulo et al. (2013) further proposed that human cognition comes from developmental, embodied interactions with the physical environment, which this application offers, primarily through problem-solving tasks. Due to the pupils' level of metacognition, determining the impact of the bodily activity outside on their cognitive development based on their statements was challenging.

Notwithstanding, some comments from pupils conveyed positive reflections about the impact of the physical environment on either their learning or well-being, such as 'You get a lot more oxygen, and the brain works better' (Girl, C, MC) and 'Being outside gives me lots of fresh air, instead of sitting inside and being quiet' (Boy, B, PS). The sensory-related expressions from the pupils underpin a grounded perspective on learning that proposes that learning processes are grounded in sensory and motor systems rather than isolated to abstractly amodal conceptual data structures (Pezzulo et al., 2013). The tone of the statements are balanced in the findings, albeit from students who did not fancy the rain, or who would rather be inside when the temperature outside was too cold, or who generally thought they would concentrate better inside. Regardless, the findings reveal expressions from the pupils around sensory experiences. Drawing on the embodied framework, we propose that sensory experiences impact pupils' learning processes, underpinning the embodied perspective on learning whereby the physical and sensory states matter, such as illustrated in the comment about the brain working better outdoors. The findings also reveal contrasting views on the impact of being outdoors and the physical environment, which underscore the variation in how children learn and their preferences for teaching methods, advocating that a pedagogical and didactic justification and reflections must be present when designing for learning through an AR game (Flobakk-Sitter & Fossum, 2023). We, therefore, assert that the variation in methods is vital when planning activities. Nevertheless, Skage and Dyrstad (2016) emphasised that physical activity in learning processes creates a varied and active school day, positively affects students' physical and mental health, and supports learning processes that reflections from the pupils noted previously affirm. We, therefore, propose that an AR game that facilitates bodily activity enhances embodied learning when necessary pedagogical considerations are prominent.

Embodied Learning

The findings show that the pupils who completed problem-solving tasks actively engaged with the technology and used more functions, like the video and photograph cameras. In addition, problem-solving tasks engaged the pupils in the social and physical environment. The findings demonstrated that the AR game facilitated the pupils' interaction with environmental factors and bodily states, which according to Hung et al. (2014), can positively affect learning and underscores Dourish (2001), who explained embodiment as the property of our engagement in the world that makes it meaningful. The outdoor environment provided an opportunity for embodied learning experiences during which the pupils physically interacted with the surroundings, fostering a deeper connection between the content presented through the AR application and the natural world. This embodied learning approach facilitated a more holistic understanding of mathematical concepts by integrating the virtual and physical realms. The interaction with the physical environment can be illustrated by, for example, the students using branches to demonstrate a math problem and submitting a photo as an answer in the application. Such tasks also enhance the social environment by engaging pupils in collaborative activities. Despite the argument from Skulmowski and Rey (2018) that tasks should be integrated with bodily engagement, this study's results are noteworthy in the respect that the pupils' social, environmental and bodily expressions made the lesson highly embodied; moreover, resting on Johnson-Glenberg`s (2018) argument that bodily movement, context and environment activate motor neurons that positively affect learning, the study results indicate that integration of the task might be subordinate. In line with Dourish (2001), problem-solving tasks encouraged pupils to be creative and collaborate, which made them encounter physical and social reality in their everyday world. The experience can illustrate embodiment since it captures what Dourish (2001) called a sense of phenomenological presence, wherein interactive phenomena arise from pupils' engaged participation. The application also mediates interpersonal communication and creates a social context for the pupils through technology (Dourish, 2001).

Through problem-solving tasks, the pupils will not be left passively consuming preconstructed resources or staring at a screen, an approach not aligned with an embodied view of learning. The AR game studied in this case allows and invites pupils to interact with each other and with natural materials, enhancing their bodily and emotional interactions with their peers, which, according to an embodied view, facilitates the learning process positively (Martli & Dincer, 2021; Pellas et al., 2020). The findings further showed that the lesson with the AR game could be considered highly embodied because the results validate that the pupils were physically active. According to Johnson-Glenberg (2018), that activates more neural pathways, which may also strengthen pupils' memory traces. Based on these findings, we propose that AR games can positively enhance pupils' activity levels and motivations and positively contribute to their learning process. This study shows that providing the pupils with problem-solving tasks contributes to collaboration, which enables them to actively engage by questioning, clarifying, challenging and being creative with the content in the game (Ward, 2018).

Conclusion

This study answers, in part, the call for more research on digital technology, focusing on the impact of technology on learning grounded in pedagogical and didactic thinking. In an increasingly digital world with concerns about children being inactive, seeking ways to incorporate embodied learning principles when designing for teaching with digital and interactive elements is vital. The AR-based game application gains substantial value outdoors by capitalising on the appeal of the natural environment. This approach not only enhances the effectiveness of embodied learning but also leverages the motivational aspects of outdoor education to create a dynamic and contextually rich learning experience. Based on the pupils' experiences in this study, the AR application contributes to and facilitates bodily experiences, connecting body and soul within a social and physical environment if set up with appropriate tasks. In addition, the nature of the application's character invites pupils to explore the physical surroundings, facilitating collaboration that fosters 21st-century skill development in a social environment where following an embodied perspective can enhance learning. Based on the embodied perspective, teachers must facilitate the activity and, if necessary, interact and guide pupils if troubleshooting in group dynamics should arise.

A limitation of the study that may be of interest to further studies is the lack of longitudinal cause and effect results. Addressing this would require a larger sample size to measure the learning from AR games and embodied learning. Furthermore, the study's implementation of the AR application on a rainy day is a noteworthy limitation, as adverse weather conditions can undeniably influence the participants' overall experience. The inclement weather may have impacted the pupils' engagement and comfort levels, potentially affecting their receptiveness to the AR activity. However, the weather-related limitation may offer valuable insights into the robustness and adaptability of the AR application. Moreover, despite the less-than-favourable weather conditions, the AR application was a positive experience overall, which shows the importance of facilitating embodied learning experiences.

Abbreviation

AR Augmented reality

Author contributions

Both authors ORS and HMS have made substantial contributions to the conception and design of the work. ORS did the central part of the analysis and interpretations of the data, while HMS participated and contributed to discussions during the writing process. ORS drafted the work while HMS reviewed the draft and participated in the final revisions. Both authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and analysed during the current study are available from the corresponding author upon reasonable request.

Declarations

Competing interests

The authors declare that they have no competing interests.

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