Use of Augmented Reality to Integrate Knowledge

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Abstract. Augmented reality (AR) has been shown to have a positive effect on motivation and learning. Yet, reviews of such findings continue show that AR research is being conducted within a narrow scope of learning processes. The current qualitative, exploratory case study took place in a primary school, where pupils aged 10–11 years used AR technology to summarise a learning session. The study applies a socio-constructive perspective focusing on active and collaborative learning to investigate the process. Detailed interaction analysis of talk and activities was used to investigate the extent to which and how the pupils used an AR application to integrate knowledge from the learning session. The findings show that the pupils expanded issues, made relations between them and put them into a larger context in a way that can be characterised as a process of integrating knowledge.

Keywords: Augmented Reality, Learning Processes, Primary School, Qualitative Method

1 Introduction

Augmented reality (AR) has been shown to have a captivating effect on users [26, 34], and the amount of research on its use has increased over the last 10–15 years [1, 27, 35]. AR has been studied in various domains and contexts, such as STEM [15], arts and humanities [13], vocational training [5], informal settings [14] and others [1].

In general, reviews and meta-analyses have identified positive results in terms of learning outcomes and motivation [1, 13, 15, 31], but challenges have also been reported, including usability issues [15] and methodological issues, such as the consequences of positive attitudes to technology and the novelty effect [1, 34], which may hamper the results from experiments.

In their review of 28 AR studies on STEM learning, Ibáñez and Delgado-Kloos [15] identified a lack of student assistance, learning structure and student collaboration in the studies and called for new insights into how learning experiences take place in STEM learning [15, p121]. The current case study aims to explore the link between learning structure and an AR application in primary school and, in particular, how AR technology is suited to the phase where pupils are to sum up, re-examine and get an overview of a specific subject. This is done through a detailed study of pupil interaction as they work in pairs.

Augmented reality is a technology that presents an overlay to objects in the real world. This implies that the concrete physical environment, is joined in different ways with the digital overlay. More generally, we can see AR as filling a continuum between reality without digital technology and completely immersive virtual reality (VR) [28]. In such a case, we can expect that the use of technology will transfer us to a completely different reality, in principle detached from the physical context we find ourselves in. In this continuum, we can have AR where technology dominates the experience, with the physical reality in the background, and on the other hand, we can have less intrusive technology where the physical reality has a more prominent position. This dimension makes AR the archetypal hybrid environment. The presence of a physical object combined with a digital application, where they are both tools for interaction and information, marries the physical and the digital in a way that sets the stage for a potential hybrid user experience.

As part of what characterises AR, interaction is mostly implicit and incorporated into the activities that learners engage in. Since the immediate physical reality context is a part of the experience, any interaction with the technology will have to consider the presence of physical objects. If the physical object is a building, moving around the building with, for example, a mobile phone directed towards the object, the visual representation on the phone's screen will have to change and gradually show new parts of the overlay of the building as the user moves around it. So, similar to VR, the activity the user engages in is also implicitly interactive, and in the case of AR, it will be related to the physical world. AR is also often designed with explicit interactions, such as selecting different types of overlays.

AR technology can be divided into marker-based and location-based (or marker-less) classes [4]. A marker can be a QR code or another visual object that the camera on the AR tool can detect. The activity in the application is then triggered by this marker, and the physical relation between the marker and the technology (e.g. changing angles, turning, moving closer/further away) can apply to the technology as well as the marker. The marker-less type of AR uses technology that can determine positions, such as GPS tracking, RFID or other types of sensor technology, and the application will show information determined by the relative (e.g. RFID) or absolute (e.g. GPS) position.

In the case reported here, the physical component of the AR system is a book [16], and a page in the book provides the marker. The pupils have tablet computers that they can position over a page in their natural science physical textbooks. When doing so, the camera captures the pattern of the page and, as a result, digital representations related to the content described in the book will appear on the screen positioned over the book. This makes the relation between the physical and the virtual more abstract in this AR application than the better-known overlays of, for instance, a geographical area [23] or VR/AR glasses for medical training [32].

In this study, fifth grade pupils (aged 10–11 years) use AR technology in the last part of a session in which they learn about the heart and the circulatory system. They work together in pairs and are observed by video. They use tablets equipped with an AR application that is triggered by the pages in their textbook. This study investigates how the pupils explore the material in the AR application and, in particular, how they can use the system as a tool to integrate previous information and knowledge. The study pursues the following research question:

- How are primary school pupils able to use AR as a tool to integrate knowledge?

How the pupils integrate knowledge, the interactions, as combined talk and use of the tablets, are studied and analysed in detail. This is done to study interactive meaning-making and how understanding develops as a form of reflection in action [33].

2 Studies of Augmented Reality in Education

The use of augmented reality for learning has been investigated in several meta-analyses and reviews over the last decade. Akçayır and Akçayır [1] showed how, since 2013, there has been an increase in studies of AR used for learning purposes. They found positive results in their review, showing how AR can enhance learning processes and outcomes and also increase motivation among students. For instance, Lu and Liu [22] observed that students learned through play. The review [1] reported that of the 68 studies, half of which were in school settings (K12), 32 studies documented enhanced learning achievement.

Ibáñez and Delgado-Kloos [15] also identified an increase in studies of AR for learning over the seven years that they included in their review (2010–2017). Focusing on STEM learning, they categorised 28 studies following a pedagogical structure of presentation, discovery or cooperative/collaborative learning. They found that the studies were mainly about remembering facts and content, and they called for future work to provide insights into learning experiences and 'deepened understanding' in STEM learning [15, p121]. Following some of the same lines of investigation, Bower et al. [2] argued that studies are too restricted when they look at current technology and should aim for the use of AR that can 'contribute to the ultimate growth of students and [...] higher order thinking capabilities' [2, p12].

Comparing AR use to other pedagogical strategies in their review, including the use of other technological resources, Garzón and Acevedo [13] related student score improvement with the use of AR. In a meta-analysis of 64 quantitative studies, 19 of which were in primary education, they found a general effect size of 0.68 that corresponded to a medium effect. Due to different research designs, only 48 studies could be a part of the comparative measures. Here, AR outperformed other technical interventions, such as different types of games, videos, animations and other learning objects. Still, they found the effect size to be diminished at lower levels. Studying vocational learning students in the upper secondary age segment, the review of AR by Chiang et al. [5] provided more positive results attributed to AR, which seemed to be in line with students aged over 15–16 years having the best results from using such applications.

Investigating how textbooks may be enhanced by AR, Ivanova et al. [16] followed the same design approach as the study reported here. In the 'Augmented reality interactive textbook', the models of different equipment for mechanical engineers were visualised as 3D models and animations, although only technical testing was done, and no actual learning sessions were reported. Nevertheless, the study was an early showcase of the viability of the book-based AR approach.

Studying students in an elementary school, Zhang et al. [38] found that the use of AR contributed to a narrowing standard deviation in the results of pupils; that is, it lifted lower achievers but was possibly less useful for high achievers, although the results were formulated in tentative terms.

Based on overall positive reports of the use of AR (see e.g. [5, 21, 37]), Radu [31] introduced some nuances when reviewing 26 publications. The author underlined how the unique designs for each AR application were central factors for the learning benefit. Related to this finding, Radu found that 3D and kinaesthetic content was suitable material for AR learning, but this was less so with textual content and 2D simulations.

Chiang et al. [6] studied primary school pupils engaging in inquiry learning and found that a mix of reality and virtuality supported productive learning processes. In particular, they emphasised how AR brought digital support into a relevant context; in this case, information about plants could be studied in their natural habitat. They also contrasted the use of AR with the time that was wasted by browsing through a great deal of information before identifying any of relevance. This in-situ characteristic, that is, information being brought in at the right place and at the right time, was also emphasised by Kuru Gönen and Zeybek [21] in a different domain, namely foreign language learning. In addition, the participants reported that the abstract nature of the concepts became more concrete and real in the AR environment as they studied.

In an experimental test of first grade primary school pupils learning geometry, Yousef [36] found improved results in motivation and creativity in the group using AR compared to the control group using physical manipulatives. The article even characterised the pupils as having an 'optimal mindset for learning while [they] utilized [the] AR application' [36, p975]. The article also found that AR could be particularly useful to motivate pupils for less popular subjects, which was characterised as 're-motivation'.

In sum, the different reviews, meta-studies and individual cases showed that AR applications generally result in positive learning benefits and enhanced motivation. The review of Ibáñez and Delgado-Kloos [15] showed how the initial presentation of a subject, discovery or cooperative/collaborative learning dominated their review, and they called for future research to be 'deeper' and also to emphasise the relation between the use of technology and the learning structure. This perspective was also brought forward by Bower et al. [2], who argued for the use of AR for expansive learning processes. This notion of broadening the scope of AR studies and the idea of Radu [31] of linking studies to real life curricula form the basis for this study.

3 Theoretical approach

This study applies a socio-constructive perspective on learning processes [18]. Central to the study is the idea of learning through pupils' own activity, such as talk and gesturing, and it focuses on exploring how pupils can build on their existing knowledge to develop new insights [10]. This study investigates the integration of knowledge as a general constructive idea that new knowledge will have to build on existing knowledge and be integrated with this to form new insights. Many scholars have underlined the integration of knowledge as a core process of learning [9, 24, 29, 30], and the idea also underlies the notion of deeper learning that is considered important in our technology-intensive society [3].

Elaborate prescriptive [7] and descriptive [11] theories about the process of integrating knowledge will not be covered in any depth here. Still, underlying the ideas of 'incorporation and displacement' [11] of 'knowledge in pieces' [9] as a process of conceptual learning resonates with 'distinguish and link' ideas in knowledge integration [23]. Without doing proper justice to any of these well-developed theories, the idea of relating pieces of knowledge to each other can be extracted as a common element. From this theoretical backdrop, the study reported here explores how augmented reality can contribute as a facilitator to building knowledge as a process of learning beyond the declarative stage and towards the integration of knowledge.

4 The Case

This study is based on the use of Ludenso Explore, an AR application based on Unity as a software development environment. In collaboration with different publishing houses, Ludenso developed a drag-and-drop solution with which publishers of paper books can link different types of media content with a QR code or a particular page in a book. The media content and meta-data are loaded onto the Ludenso backend running Microsoft Azure. After installing the Ludenso app on mobile equipment such as a mobile phone or a tablet computer, standard software in Android (ARCore) or iOS (ARKit) will be triggered, and the user can activate content when the app recognises a page or QR code.

Figure 1: Illustration of how the pupils can interact using a book, here with mobile phones. They used tablets during the case study

In this study, a fifth grade class (pupils aged 10–11 years) was observed as they used a 3D animation of the human heart triggered by a page in their textbooks. The use of the AR application concluded a 75-minute session in which the pupils had been learning about the heart and the circulatory system. Prior to the concluding session, the pupils spent 60 minutes on specific activities organised by the teacher. These activities were varied, including presentations to the class by the teacher, discussions among the whole class, carrying out work and discussions in pairs and individual reading time. The issues covered were the substance of blood and bleeding, the human waste system and the circulatory systems. Plenary filled most of the 60 minutes, with the teacher presenting and there being discussions among pupils and with the teacher in the class. Consequently, at the point where the pupils started to use the AR application, they had been exposed to different issues of the heart and the circulatory system in different ways and had a varied set of opportunities to take in, share and express knowledge about the issues. The activities in the last AR session were structured with a set of questions given on a sheet of paper to the pupils while they worked with the book and the tablet.

Figure 2: Illustration of how the pupils interacted with the tablet

The AR application is marker-based—in this case, the book page is the marker recognised by the app and triggers an animation of the heart in 3D. The pupils hold a tablet over the appropriate page in the book, the camera gets the page in focus and the app triggers a digital representation—in this case, a 3D model of the heart. The pupils then use the tablet as a 'lens' to look into the heart from different angles. When they move the tablet or the book, the model on the screen moves accordingly, and the general idea is that the pupils can experience using the tablet as a 'window' around the object rising from the book and see it from different angles.

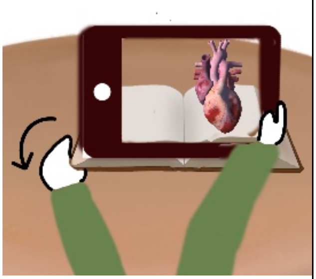
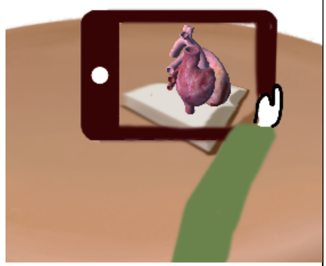
The heart from the front	From the right (book turned)
	

Figure 3

There are two models, one showing the heart from the outside and one showing it from the inside. Initially, the heart is shown from the outside, but the pupils can select the other model, which shows the inside of the heart (see Figure 5). The model showing the heart from the inside aims to give the impression that the user is inside the heart, looking at the different elements from within as they move the tablet or the book. Both models also show the veins and arteries inflowing to and outflowing from the heart (see Figure 5).

As the link needs to be preserved between the book and the tablet by the camera having contact with the relevant page in the book for the model to appear on the screen, the pupils cannot move the tablet away or tilt it so that the camera loses contact with the page. If the camera loses contact, the model disappears, yet it quickly reappears if the page again enters the scope of the camera. The model is an animation, showing the heart muscle beating and the cardiac valves opening and closing. The pupils can also zoom in on the heart in all the different positions during the animation as well as turn it in different directions (see Figure 6).

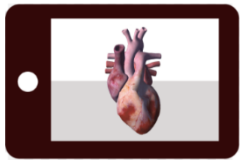
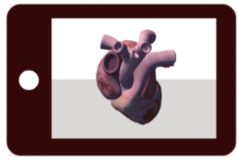
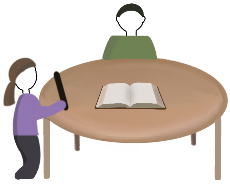
The heart from below	The heart from the front	The heart from above
		
		

Figure 4

To structure the session with the use of the AR application, the pupils were given a sheet of paper with a series of questions about the heart and the cardiac system that included ‘Find the aorta in the model’, ‘Agree on the direction of the blood’s movement through the heart’ and ‘Where is the pulmonary artery?’.

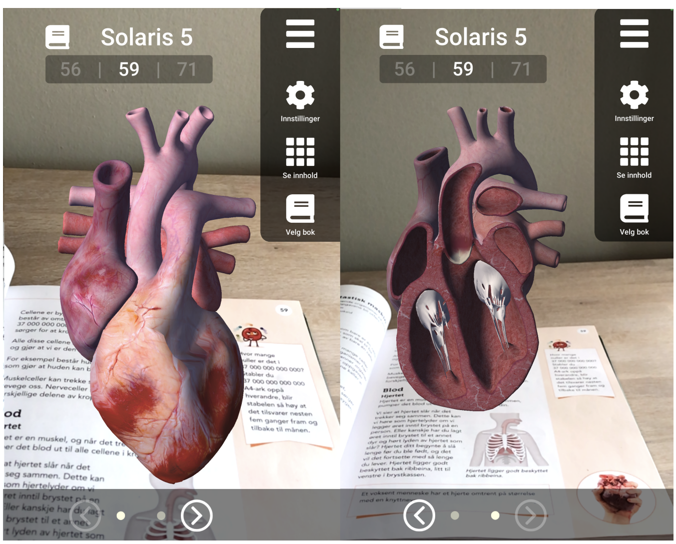


Figure 5: Two views of the beating heart, the inside and the outside

5 Method

The data in this study were collected through the use of video/audio equipment. Two pairs of pupils were taken out of the class and assigned to two smaller group rooms for observation. For 15 minutes each, they used the model, and this part was captured with video and sound and observed by a researcher operating the equipment in the room. For background information, the pre-sessions were observed.

The teacher selected the two groups (there were originally three groups, but due to illness, only two completed the assignment). According to the teacher's estimation, Tom and Elise (Excerpts 1 and 3) were considered to be medium- to low-performing pupils and Celeste and Lena (Excerpts 2 and 4) high-performing pupils.

Thirty minutes of video observation (15 minutes for each pair) was transcribed in full. This resulted in 159 utterances by Tom and Elise and 205 utterances by Celeste and Lena. To explore the integration of knowledge as a process, the analytical procedure was directed at how the pupils engaged in interactive meaning-making, that is, how they explored issues verbally and used the technology to investigate those issues. The passages selected were based on the criteria that the pupils were taking an active approach to the model by identifying parts of it and/or moving the model to investigate it while also verbally explaining what they saw. In the initial report, nine excerpts were selected, which were reduced to four and shortened for this article. The four excerpts were chosen to span some of the different nuances of the activities and discussions the pupils engaged in within the criteria above. To investigate the activity on a level of interactive meaning-making in a triangle consisting of technology and the two individuals collaborating, the interaction analysis [8, 17] was extended with activity descriptions to examine how the pupils moved and acted during the verbal exchanges. The aim was to elicit the reasoning the pupils engaged in when they communicated with peers supported by an augmented reality application, framed by the issues brought forward in the research question.

6 Using the AR Tool to Answer Questions

The data reported below are from the final part of the session, where the pupils were learning about the heart and the circulatory systems. They had opportunities in the session preceding this to learn about most of the questions asked on the paper they were given. Here, they are specifically asked to use the AR application to answer the questions.

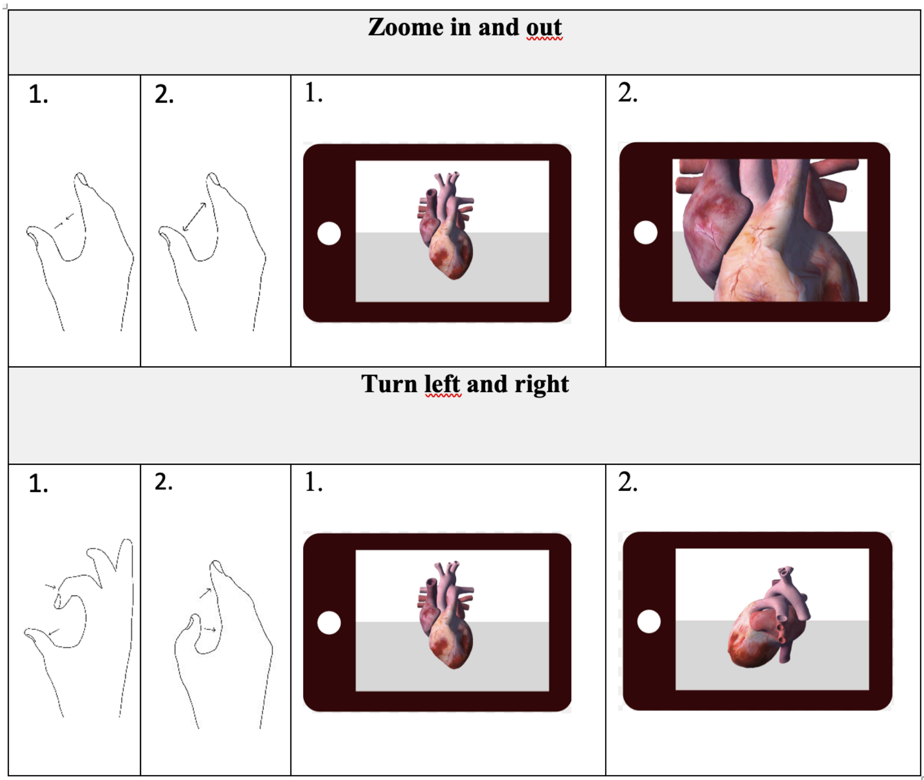


Figure 6: Illustrations of how the pupils can zoom and turn

In Excerpt 1, Elise and Tom are using the app to find the aorta (the main vessel that takes blood from the heart to the body) in the model. They have a tablet each and are using them separately, but they are sitting close together and can easily look at each other's screens.

Table 1: Excerpt 1

1: Elise: Aorta … It is probably that one.	*a: Tom lifts the tablet, scans the page and gets the model of the heart.*
2: Tom: It is that one.	*b: Elise does the same with her tablet.*
3: Elise: It is that thing that enters into the neck.	*c: Elise points to her face and downwards and then up again towards*

4: Elise: No, it is not the neck, it is the big blood vessel.	*her neck.*
	D: Tom gets up, hovers the tablet over the book and studies the model.
5: Elise: That one.	*E: Elise looks at Tom's screen*
6: Tom: That one.	*F: Tom lifts the tablet again and looks at the model. He zooms in and out with his hands.*
7: Elise: It is quite big.	
8: Elise: It seems that it is heading straight up and is pretty big.	*G: Elise looks at the model on her tablet.*

Here, the pupils explore the model on their own screens, although Elise also looks at Tom's screen (E) to confirm that they are both referring to the same object in the model. Elise corrects herself in 4 and 5, without Tom interfering, to find the right vessel in the model. She also uses herself as a reference through her gestures, trying to place the aorta in her own body. Tom is actively zooming in and out (F), which may be a way to study details and also to show Elise where it is. It is mainly Elise who does the talking, acting also with her body, and Tom uses the model to find the vessel. Towards the end of the excerpt, they agree on where aorta is in the model.

The excerpt shows a session in which the pupils are able to use the model in a way that puts the question of finding the aorta in the model into context in two ways. First, Elise refers to her own body through her gestures, placing the heart and aorta onto herself, inspired by the model. Second, Elise refers to the aorta as something big, implicitly comparing it to the other vessels and objects on the screen, and also comments on the direction of the vessel, thereby linking it to her gestures earlier in the excerpt.

In Excerpt 2, Celeste and Lena work on the same task of finding the aorta in the model. Unlike the first pair, they share a tablet and work together as they try to find it.

Table 2: Excerpt 2

9: Celeste: Aorta … It is that one?	*H: Celeste points to the screen.*
10: Lena: I think it is better to turn it. Let's see.	*I: Lena turns the book, and the model turns on the screen.*
11: Celeste: No, this is not the aorta. Is it the aorta?	
12: Lena: No, the one in the middle.	*J: Lena points at the aorta and moves her finger to follow the blood vessel upwards.*
13: Celeste: Yes, the one that is divided into three.	

In this excerpt, Celeste and Lena follow a similar path to that of Elise and Tom in Excerpt 1, initially selecting the wrong part of the model and then correcting themselves and finding the right vessel. Yet, compared to the previous pair, Celeste and Lena exchange more views, sharing the tablet and having a brief discussion to find the answer. They take an active approach to the model by pointing (H and J) and turning the book (I) to see the parts they are interested in. Celeste seems to initially have identified the wrong one (9) and then corrects herself (11), and she is also helped by Lena, who both uses her finger (J) and explains the position of aorta (12). Celeste confirms this by describing the vessel (13) so they both can agree on what they are talking about.

Sharing the tablet seems to make sharing information easier, and the excerpts have exchanges of views. Each student follows the reasoning of their partner, and they reach a common conclusion. By comparing the vessels in the model, talking about which it might be and which it is not, they make comparative judgements. They give the aorta different characteristics, such as ‘in the middle’ (12) and ‘divided into three’ (13), but they still agree on identifying the right one. First, the excerpts show how the AR application responds adequately as the pupils use it to answer the question about the aorta and can also be used for sharing information, exchanging views and engaging in deictic activities. Second, as in Excerpt 1, the exchange shows how the students are able to compare and contrast while finding answers to the question.

In Excerpt 3, the pupils answer the question about how the blood moves in the model. It was formulated by the teacher so that they had to agree on an answer. Here, the first pair, who have two tablets, occasionally look at each other’s screens. At this point, none of them has found the second view of the model, where they can see the inside of the heart (see Figure 3).

Table 3: Excerpt 3

14: Elise: Three moves up. 15: Elise: They go out there, so I believe, they go in there. 16: Tom: Mm. 17: Elise: And I believe that they move into the other side as well. With the ones that are red-pink-like. The ones that come out. 18: Tom: I believe the blood is stored in the big white one [right heart ventricle]. 19: Elise: Yes, and then it moves up. 20: Elise: So, they go, like. Take it down. 21: Elise: They look like a T. I believe it moves to the lungs, and the others go to the body … Those	*K: Elise points with three fingers at the top of the model [the three arteries branching from aorta].* *L: Elise points at the veins at the left of the model and follows them with her finger.* *M: Tom turns the model around, points to the front-left chamber and makes a circle in the area.* *N: Tom is zooming in and out.* *O: Elise touches Tom’s shoulder to get his attention. Tom then looks at Elise’s screen.* *P: Elise points to the lung arteries in the model.*

on the top there. 22: Tom: Mm.	

Similar to Excerpt 1, it is Elise who does most of the talking. She refers to three arteries branching out of the aorta through which blood moves out of the heart in the model and then refers to the veins on the side where the blood flows into the heart (14, 15, K, L). When Tom refers to the 'big white one' (14), it is the right heart ventricle that is large (filled with blood) in one part of the cycle in the amination. Elise explains how the blood then moves to the lungs via the arteries (the T refers to how the vessel divides in two lung arteries). She also refers to the arteries of systemic circulation in 21 when she refers to the arteries that 'go to the body'.

Here, the pair, led by Elise, go through pulmonary circulation from the right chambers of the heart to the lungs and back to the left chambers. Elise also includes the circulation of blood through the whole body, which seems to be an effort to take in the overall movement of the blood, as it is reflected in the different vessels that move in and out of the heart. She uses a mix of verbal utterances and gestures to explain and convince Tom, possibly also explaining it to herself, as she points to the model and insists on getting his confirmation of her reasoning. Tom seems to miss how the blood moves and sees the heart more as 'storage' than a muscle pump, but he expresses agreement with Elise in the end.

Even though it is not a large step from the question of blood moving through the heart to the ways the blood moves in the body in the two circular systems, it is still a step beyond what they are asked by the teacher. Triggered by looking at the screen (in O), Elise gets Tom to show her the T-formation, and it seems to contribute to the sequence (19–21) where Elise reasons about the blood circulating to the lungs, thereby expanding slightly on the question from the teacher.

In Excerpt 4, Lena and Celeste work on the same task of determining how the blood moves in the heart. Unlike the other pair, they have discovered how to see the heart from the inside and use this function in this excerpt. They share one tablet, and then can easily observe each other's gestures to the model as they develop their reasoning.

Table 4: Excerpt 4

23: Lena: Then it moves out. 24: Celeste: Out? No, it does not move out, I think... 25: Lena: Ok. 26: Celeste: I believe it moves further ... no, it cannot move further ... 27: Lena: It moves ... yes, it moves in. 28: Celeste: But, there are no holes in the model of any kind. 29: Celeste: So how does the blood move	*Q: Lena points to the model.* *R: Celeste points to the model.* *S: Celeste points again.*

out? 30: Lena: It [the blood] moves in there, and then it is pumped out. And then it moves to the heart. 31: Lena: And then it pumps in with oxygen. 32: Celeste: In there? 33: Lena: And then out. 34: Celeste: To the three blood vessels. 35: Lena: Yes. 36: Celeste: Mm.	*T: Lena points up and down repeatedly at the-model.* *U: Celeste points again.* *V: Lena points again.*

The concern here, for Celeste in particular, is that she does not see the way that the blood moves out of the heart. In 24, 26, 28 and 29, she asks Lena (and possibly herself) about this issue. It seems as though she believes that all the vessels pictured in the model send blood into the heart, but she does not see how the blood leaves the heart again. This seems to be similar to the idea of the heart as 'storage' that Tom mentions in Excerpt 3 (18). Lena explains and points to the model (in particular, in 30, 31 and 33 and in Q, T and V) and also refers to how pulmonary circulation supplies the blood with oxygen (31) and then pumps it out and streams it through the aorta. Celeste also confirms that she agrees with this interpretation by referring to how the aorta is divided into three in the model (34). The pair also confirm their mutual agreement towards the end of the excerpt (35 and 36).

In this excerpt, there is a specific critical question triggered by Celeste's understanding that the vessels only lead blood into the heart, and she does not find any way that the blood can move out again. Lena answers by expanding the question of movement in the heart to also refer to the circulatory systems and how the blood is supplied with oxygen. None of this is shown in the model of the heart. Lena uses the heart pumping on the screen as she talks about how the blood moves, and the gestures and the verbal explanation lead them to a common conclusion. Celeste is able to give concrete proof and an acknowledgement of her understanding by referring to the division of aorta in the model. They also exchange a high-five after the excerpt, indicating that they have concluded their task.

First, this excerpt shows how the pupils actively use pointing (deictic activity) to get the attention of the other partner regarding specific parts of the model. Second, the issue is extended to the circulatory systems and, in particular, how the uptake of oxygen in the blood is a function of pulmonary circulation.

Summing up the excerpts, we find that the pupils, from two rather concrete questions ('Find the aorta in the model' in Excerpts 1 and 2 and 'Agree on the direction the blood moves through the heart' in Excerpts 3 and 4) expand the tasks that they are given. They include the two circulatory systems of the body, including oxygen supply (Excerpt 4) and how blood is channelled around in the body (Excerpts 3 and 4). Elise (in Excerpt 1) also links the position of the aorta in the model to the position of the aorta in her own body. All of them take an active approach to the model, pointing, turning the book and the tablet and zooming in and out as they reason around the issues that the questions and the model cover. In this expanding activity of talk and deictic activity, the pupils also put issues of the heart into the context of circulatory systems and oxygen uptake, thereby insisting on not just mechanically answering the factual questions that are put to them.

7 Discussion

This study investigates the extent to which and how primary school pupils can use AR technology to integrate knowledge. As presented in the review section, existing studies have shown how AR applications generally result in positive learning benefits and enhanced motivation. Yet, the scope of the studies is narrow [15, 25], and investigations of how this type of technology can be used to support more conceptual learning, such as the integration of knowledge, are scarce. In addition, studies linking learning structure with AR technology are limited [15]. In this study, the pupils use AR late in the learning structure, enabling an investigation into how they can use it as a tool to integrate the pieces of knowledge they had worked on earlier in the session.

The detailed study of the two pairs reported here shows that they were active physically (pointing at and manoeuvring the tablet) and verbally. When they were presented with the questions and the technology was made available to them, they were immediately triggered and began to explore. It could be observed that both pairs were focused and stuck to the task of answering a series of questions throughout the session. The AR sessions only lasted 15 minutes and took place after 60 minutes of class activity. The questions that were answered were specific, namely to find the aorta in the model (Excerpts 1 and 2) and to agree on the direction in which the blood moves through the heart (Excerpts 3 and 4); still, they magnified the questions and brought in the 'environment' in which the heart operates (i.e. the body), including the two circulatory systems; how blood is infused with oxygen; and how the aorta compares to other blood vessels. These discussions were not advanced, but they were still at a comparatively high level for pupils aged 10–11 years.

The book seemed mainly to work as a tool that the pupils could use to get the model to appear on their tablet and to turn it on the screen, as turning the book also triggered the model to turn on the screen. It did not play an important role in terms of information or as a source for learning in this phase. So, by only using the model, the pupils still expanded on the issues they identified and put them into a broader context. Elise and Tom used the model as a reference point in Excerpt 1, and Elise related it to her body, which clearly went beyond the question, and reflected on the size and form of the aorta. In Excerpt 2, however, the expansion seemed more limited. Here, the activity was engaged and directed towards the question of finding the aorta, but it was also comparative, and Celeste and Lena characterised the vessel. In Excerpt 3, the task was explicitly collaborative, challenging the pairs to agree on the direction of the blood. Elise and Tom referred to the form of the vessels, thereby acknowledging the facts for each other and themselves as they expanded on the specific question of direction. In Excerpt 4, the model gave Celeste and Lena a challenge, as they found the need to collaborate and discuss lung arteries, the form of vessels and the infusion of oxygen as they explored the model.

Based on this, what could be the reason for the tendency to expand on and put issues into context that we identified when the pupils used AR in the concluding session? One reason might have been the well-prepared summing-up session. We could not observe direct references to the previous sessions, yet previous knowledge built in these sessions clearly had a role when both pairs used the model of the heart. The pupils were able to talk about the questions and the models beyond the information that was immediately available. The preceding activities, which were more specific, covering issues such as blood and the pulmonary circulatory system, seemed to have equipped the pupils to use the AR model and to explore these issues in context. Yet, the specifics of the application and content may also have had characteristics that contributed.

The model enabled, to some extent, an 'exhaustive' view of the heart. This does not mean that the model contained all the information about the heart, but the pupils could gain an impression of wholeness by being able to see the heart from 'all' different angles, inside and outside. The application delivered stability that enabled the investigation. The pupils interacted with the heart by zooming in and turning it on the screen more than they actually moved the tablet. Interaction as we usually know it, such as pushing buttons and searching for and finding items in lists and menus, was very limited here, and therefore did not interfere with the investigating activity of studying the object. The direct interactive possibilities of finger zooming and turning also seemed to have a focusing effect rather than being a possibly diverging activity of finding new interactive opportunities, such as searching, clicking and looking for new options, as seen as a form of 'hyperinteractivity' in other studies [20]. The pupils stayed on target for the whole session. Kuru Gönen and Zeybek [21] found that AR in language learning had the similar effect of making abstract issues more concrete and real. In the abstract world of language, this is an achievement, but it was also the functioning and movement of the animated model that seems to have made the issues of the heart and circulatory systems more concrete for the pupils. In particular, how both pairs were physically active, by pointing, turning, zooming in and out and relating the model with the body, indicates this turn towards making the issues more tangible. This directness enabled the pupils to engage in what, at least in some sequences, looked like a seamless process with the content in focus. They were able to form links between elements in the content and even between the content and their own bodies (Excerpt 1). Both pairs were able to expand on the issue, albeit still within the topic, which can be seen as a consequence of the technology, which was restricted to the model visualised by the AR technology. Linking and expanding within a topic resemble some of the processes of incorporation (making relations) and displacement (assessing the lack of relevance when needed) brought forward in conceptual learning and also linking and distinguishing from Linn and Eylon [24].

Usability issues are among the most reported 'downsides' when it comes to AR [1, 34]. Such problems were limited here, and the pupils seemed to experience being free to explore, point, refer to parts of the model and also link information to their own bodies. On occasions, both pairs lost contact with the book, triggering the model to disappear, but they immediately moved the tablet closer to the book and regained the model on the screen. Here, it is also interesting to note that it was the explicit interaction of selecting between different views by using an arrow that posed problems for one of the pairs. Tom and Elise did not discover that they could shift the view or look at the inside of the heart until late in the session, which limited some of their reasoning. So, the most important usability problem observed was outside of the implicit AR-related interaction.

In addition to the explanations related to the content, interaction and technology, it is also important to add a more structural reasoning [13]. The learning sequence set up by the teacher enabled summing-up activities, stimulating a process of knowledge integration. The pupils had already gone through the issues and were well-prepared to engage in this activity at this stage of the structure.

One of the most commonly reported effects of AR is within what is called the 'affective domain' [15, 27]. Interest, enthusiasm and increased activity are components of this category. It is reasonable to see that this effect has a role when pupils expand their tasks and relate them to other issues in the vicinity of the questions posed. The AR session was towards the end of a rather long session for this age group, yet they stayed focused on the tasks. The other side of an increase in interaction is that the activity may go beyond the purpose of learning processes. This is known, for example, as the wandering mouse problem from educational games [19], where interactivity as trial and error can hamper learning processes rather than facilitate them. The pupils in this case used the AR application in a matter-of-fact way during the session, which is also tangible in the excerpts, maybe with an exception of the rather intensive zooming in and out in one excerpt. So, playful use without direction, which can be seen in other rich interactive learning environments [12] and be an issue in this age group, was very limited here. This may also have been due to the limited possibilities available in this type of integrated interaction, which is typically also the case in augmented reality in general.

8 Conclusions, Limitations and Further Work

The point of departure of this study was that AR has a potential to be used in a variety of learning situations at schools. Specifically, we investigated how primary school pupils can use AR as a tool to integrate knowledge. This exploratory study indicated that this type of technology may also stimulate learning towards the end of a learning session. The pupils used AR as a tool to sum up, reiterate and put the questions they were answering into a broader context. Even though the questions they were given by the teacher were specific and factual, the use of AR technology seemed to draw the pupils into opening up discussions and engaging in activities to relate the different elements to each other, also bringing in the relevant context within the topic in question.

AR interaction in this case was limited and worked mostly as a virtual window into the heart, both from the inside and the outside. This seemed to lead the pupils into focused investigations, even after a relatively long session for this age group. The well-planned structure of preparing the pupils before the AR session enabled them to answer the questions in this environment and also engage in interaction and talk, observed as processes of knowledge integration.

This was an exploratory study of how it is possible to use AR technology. Although learning outcome was not measured, activity and talk were observed in processes that indicated the integration of knowledge in a socio-constructive perspective. The study shows a direction for AR learning processes that seems viable and promising. In particular, this seems to be the case when the technology is used in the process to integrate previously fragmented knowledge by applying it in a well-prepared session where the pupils/students can reiterate, expand on the topic and form relations between pieces of knowledge while also being motivated to put this knowledge into context. Important future work would include exploring the relationship between the digital and the physical. In this study, the physical book gradually moved into the background for the pupils. Given that the book contained relevant and important information for them, presented in a way that supplemented the digital, how should the design of the digital (and physical) stimulate this alternation? A related design issue is how to add features for the digital part of the hybrid environment such as operating simulators, opening objects and triggering information in context without compromising the directness inherent in the implicit interaction of 'moving around' the object as if it were present.

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