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ORIGINAL RESEARCH ARTICLE

Introducing augmented reality in early childhood literacy learning

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Augmented reality (AR) as an emerging technology has gradually been incorporated into educational contexts; however, the cases that incorporate AR into early childhood contexts are underrepresented and especially scant in the literacy domain. Aiming to measure the impact of AR on early childhood learning and motivation in the literacy domain, this study brought an application into six pre-kindergarten classrooms by introducing three experimental classrooms to an AR centre while others engaged with a two-dimensional (2D) version of the same material. Bayesian analysis revealed that rapid letter naming rates grew for all children involved in the study. It increased by 6.28% among children in the experimental AR group and 3.35% in the control 2D group. Growth in rates of motivation was similar among experimental (11.5%) and control (10.9%) groups. These findings suggest that three-dimensional images of letters might help with rapid letter naming skills, and animations available in both versions may be the reason of increases in motivation. Teacher interviews presented positive views towards AR, and instructional implications were provided by teachers for incorporating the technology into early childhood classrooms.

Keywords: augmented reality; rapid letter naming; motivation; literacy skills; Bayesian analysis

Introduction

Emerging educational technologies have brought new dynamics to classrooms and provided teachers more options for pedagogical activities. Augmented reality (AR), as one of the newly emerged platforms in the educational technology field, has gradually drawn more attention from researchers (Akçayır and Akçayır 2017; Wang, Lee, and Ju 2019; Wei et al. 2015).

Although the technology itself has been around for a decade, the recent boom in mobile technology made AR more accessible to the public and educational fields (Sommerauer and Müller 2014). Different from virtual reality, which creates an immersive environment by incorporating a headset, AR superimposes the virtual images over the physical world and allows users to interact with those digital graphics through physical manipulation (Azuma et al. 2001). These features endow

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AR the ability to render a vivid relationship between the physical world and virtual graphics, thus providing learners a more interactive way to access learning contents (Ho et al. 2017).

Previous studies have shown benefits to engaging learners with AR due to their interactivity (Gecu-Parmaksiz and Deglialioğlu 2018; Sahin and Ozcan 2019; Wang, Lee, and Ju 2019). Gecu-Parmaksiz and Delialioğlu (2018) demonstrated that lessons assisted by AR were effective in enhancing students' spatial skills because AR gave students accesses to explore and interact with learning objects from different angles and distances. Moreover, Wang, Lee, and Ju (2019) found that when using AR picture books, AR is positively associated with higher rates of student interest. Other studies have shown a continued trend of findings that support the notion that AR is an effective tool for motivation and academic achievement (Kaya and Bicen 2019; Sahin and Ozcan 2019). Despite previous research depicting a positive image of AR's role in education, AR has yet to be incorporated extensively across content areas and age levels because AR applications are often not designed for educational purposes (Gudoniene and Rutkauskiene 2019).

This creates a need for rigorous study of AR before any large-scale implementations. If the goal of educators is to benefit students, as indicated by multiple studies, the investigations into AR should also involve diverse populations and learning contexts to gain a more comprehensive and objective view (Akçayır and Akçayır 2017; Ho et al. 2017; Kaya and Bicen 2019).

Previous researchers have conducted literature reviews about the uses of AR in different educational contexts (Akçayır and Akçayır 2017; Sirakaya and Alsancak 2018; Yuliono and Rintayati 2018). These studies showed that the research on AR was not evenly distributed across students' age groups and content areas. For instance, Akçayır and Akçayır (2017) presented that only 1 out of 68 AR studies were conducted in early childhood (EC) context. The results also resonated with the findings from another literature review conducted by Sirakaya and Alsancak (2018), where researchers went through 105 articles on educational uses of AR and found that only four articles were focused on EC, indicating EC was underrepresented in AR-related educational studies. Moreover, another implication worth noting from the literature reviews is that the most of AR studies were conducted in science, technology, engineering and mathematics (STEM)-related subjects. For instance, in Sirakaya and Alsancak's literature review (2018), 95 articles were focused on science or math education such as physics, chemistry or medical training, whereas only seven studies were about literacy or language. Therefore, the above results from multiple literature reviews revealed a research gap in AR's educational implications on EC, and especially in literacy or language arts content area. In order to examine AR's impacts and potentials deeply, the main goal of this study is to explore AR's effects on EC literacy education.

Literature review

Augmented reality in early childhood education

As AR has been gradually introduced into educational environments, its effects in the EC contexts were not thoroughly investigated. While for the few AR empirical studies that did conduct in the EC contexts, they presented positive outcomes. Several other studies have examined AR from multiple perspectives. For instance, Yilmaz

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(2016) investigated the attitudes of both young children and their teachers towards an AR incorporated educational toy based on survey, interviews and observations, and findings indicated that children presented a positive attitude towards AR because it involved pointing, responding and turning behaviours while interacting with the device, which endowed children a sense of control (Cheng and Tsai 2014). This study also indicated that AR learning technologies can be effectively used in EC education if the device is designed to match children's cognitive level. In another study, Lorusso et al. (2018) examined an AR-based learning activity that involved an application of physical cube and smart television. Twenty-five children who experienced the learning activity have shown high levels of participation, social interaction and strategic behaviours such as problem-solving. The outcomes revealed the potential of AR in improving children's intellectual skills such as cooperation and communication. Moreover, Stotz and Columba (2018) conducted an empirical study by introducing preschool students to an AR-enhanced board game to teach subitizing. The findings showed that AR provided students with positive learning experiences and students showed higher engagement as well as innate curiosity towards math. However, this study could only access a small group of participants and thus, future studies that enroll larger sample size are needed.

Augmented reality in early childhood literacy education

Although more studies about AR in the EC field are focused on STEM areas (Ibáñez and Delgado-Kloos 2018), there are still a few studies that have dived into the field of literacy. Yilmaz, Kucuk, and Goktas (2017) assessed 92 children's (aged 5 and 6 years) attitude and their story comprehension performance (SCP) after using an AR picture book. The results showed that most children reported feeling very happy when interacting with the book and all of them enjoyed the activity. Besides, the findings also revealed that children's happiness had influenced their SCP, although no correlation was found between SCP and enjoyment. This study identified the potential of AR applications in EC contexts and proved its positive acceptance among young children, while the authors also implied that children's usage of AR and its educational implications should be moderated with careful consideration of factors such as health, emotion and social interaction. Earlier studies conducted by Hornecker and Dünser (2009) and Cheng and Tsai (2014) presented similar findings, both studies revealed that children expressed a positive attitude towards the AR books. Although the outcomes demonstrated a positive attitude towards AR-involved literacy activities, there is still a gap for researchers to rigorously study its effects in delivering specific literacy skills, especially as an increasing number of AR products are being introduced to children for both school and family contexts. In a recent study, Wang, Lee, and Ju (2019) found out that despite the significant increase of children's interests in reading, AR picture books also negatively influenced children's reading concentration. It implies that more studies about AR applications are needed to provide educators a thorough lens of its impact on EC literacy learning. Moreover, such studies can also provide practical insights for educators to guide future use and will assist researchers as well as AR designers to better improve this newly emerged technology for educational purposes.

To extend the existing body of knowledge evaluating AR's impact in EC, the main goal of this study is to examine AR's effects on skills and motivation in the literacy domain. An investigation in AR's potential affordance in fostering children's rapid letter naming skills was chosen because it was considered as a fundamental and a crucial steppingstone in children's development of reading speed and fluency (Cornwall 1992), and it is also an important component in early literacy skills evaluation (UTHealth 2018). Although previous studies have evaluated AR's impacts on SCP or reading concentration, no research had investigated the effects on children's rapid letter naming skills. This study intends to address:

(1) What is the impact of AR activities on EC rapid letter naming skills?

Moreover, although prior research had evaluated young children's perceptions such as attitude towards AR, research seldom has focused on the impacts of AR on young children's motivation to acquire literacy skills (Sirakaya and Alsancak 2018; Yuliono and Rintayati 2018). Some studies argued that young children's values, expectations and motivations are domain-specific, which means different academic subjects will influence their motivation level differently (Chapman and Tunmer 1995; Wilson and Trainin 2007). Thus, this study is also interested in examining AR's impacts on children's motivation, and specifically, their motivation in the literacy learning domain:

(2) What is the impact of AR activities on EC motivation to acquire literacy skills?

Finally, AR, as an emerging educational technology, is new to EC teachers and it is important to consider their observations and comments for evaluating future uses. Thus, researchers also intended to examine teachers' feedback and reactions after incorporating AR in their classrooms to provide implications for future instructional practices in EC literacy education:

(3) What feedback emerged from teachers' first-time use of AR in the EC classroom?

Method

Participants and context

Three EC schools located in the southwestern region of the United States were recruited to participate in the study. At each location, after obtaining teacher consent, one pre-kindergarten class was randomly assigned as the experimental group that used an AR book set, and another class was randomly assigned as the control group with access to the same application and activities without the AR feature.

Data were only collected from the students after obtaining both parental consent and child assent. Parental consent was obtained by sending consent forms home with students. The children assent was obtained verbally by asking students questions like: 'Do you want to do an activity about letters?' In addition, parents and children could withdraw from participating in the study anytime simply by notifying the researcher or teacher. In total, there were 76 pre-kindergarten (3–6-year-old) students, including 39 girls and 37 boys, who participated in the study. Forty of the participants were in the three experimental classes while 36 were in the three control classes.

All sites had similar daily activities that included self-directed activity time, whole group instruction, playtime (mostly outdoor recess) and mealtimes. Although different locations did not follow identical schedules, the percentage of the day taken up by different kinds of activities was roughly equal across classrooms. Teachers often had at least one assistant in the classrooms and there was a general emphasis on letting

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children learn through play that involved sharing, pretending and solving problems. All classrooms were student-centred and often activities were led by student initiative except for the whole group reading time and transitions between locations.

Materials

The AR set used for this study was composed of a picture book, a headset and an application installed on the iPad (disruptED 2020). The contents of the book were the English alphabet with accompanying cartoon figures that represented a word that starts with the corresponding letter sound. Students in experimental groups were able to access all AR features provided by the application, and they could use the iPad camera to scan each page of the book to activate corresponding animations and sounds. The animations could be activated from different angles, distances and as many times as the student wanted, which gave them complete control over pacing and frequency. Navigation through the book is by turning a new page and scan the contents. The final page demonstrates all the 26 letters, and when this page was triggered, a letter song would play. Students in the control groups were only able to access the two-dimensional (2D) mode of the application; this mode does not require any interaction with the physical book and all animations are played automatically on the device once students access a certain page. Navigation through the contents is controlled by tapping the arrow on each page. The learning content and animations were the same across each version, the only difference being the AR features (see Figure 1).

Research design

The design of this study followed a constructivist learning perspective. The constructivism indicates that the learners construct their knowledge by interacting with the contexts and they should take the main role in learning activities (Tynjala 1999). The role of instructors, in this case, should be a facilitator to assist students in gaining new knowledge instead of providing direct instructions (Hmelo-Silver 2003). This design allows students to explore the AR picture book freely which eliminates the possible instructional influences presented by instructors.

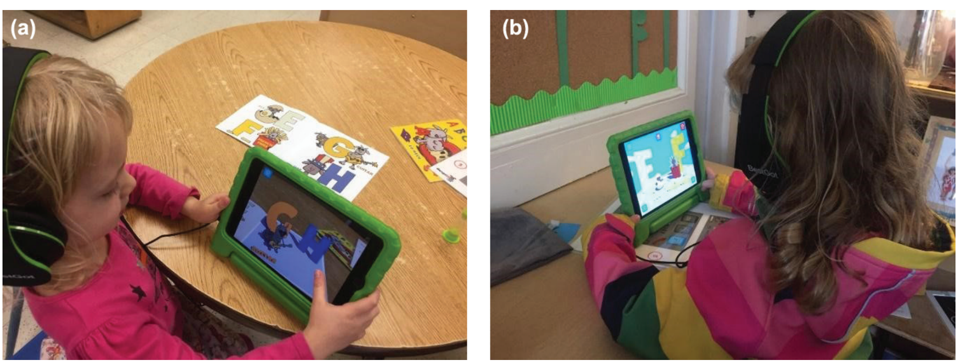

Figure 1. Students' interaction with AR (left) and 2D version (right).

In each of the three experimental classes, an AR picture book activity centre was set up for 6 weeks (see Figure 2). These centres consisted of an iPad, a picture book, a roster and a timer. The timer on the table was used to avoid excessive screen time as suggested by Yilmaz, Kucuk, and Goktas (2017); these items were all placed in an area of the classroom that students were already familiar with. Students had the full autonomy to decide when to interact with the AR picture book centre. The role of researchers and instructors is to facilitate the activities by ensuring that students are taking turns, marked their names on the roaster and abided the time limit. Students were allowed to interact with the materials for up to 10 min and as many as three times per day. Researchers and instructors would intervene when students passed time limits or intend to take more than three turns in a day to prevent excessive screen time.

The same centre was facilitated by researchers and instructors in each of the three control classrooms with the exception of a picture book. The three-dimensional (3D) AR shapes were not able to be triggered without the physical book, and this ensured students in the control group would not interact with the AR feature.

Data collection and analysis

All six classrooms participated in identical pre- and post-assessments delivered by researchers. Semi-structured interviews were conducted to gather teacher thoughts

Figure 2. An example of the AR centre in the classrooms.

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and feedback both before and after the implementation of an AR centre in their classroom. During the time of the study, researchers collected anecdotal observations, pictures and videos of behaviours observed among students using the AR centre.

To assess letter recognition skills, students were asked to identify as many letters as possible from a PowerPoint to determine if there were any gains in rapid letter naming throughout the study. On each slide of the PowerPoint, students were shown a letter for 5 s, and researchers then recorded whether the letter was named correctly or not within the timeframe.

As for motivation to acquire literacy skills, previous studies found methodological difficulties in measuring children's motivation using self-report manners such as questionnaires and interviews (Roberts and Sadler 2019). These approaches are not feasible to conduct with young children who are still developing their language and verbal skills because motivation is constructed as an internal state, it is challenging for children to express it verbally (Chang and Burns 2005). Thus, previous research that evaluated EC motivation applied indirect approaches including using observational data (Berhenke et al. 2011) or inquired estimated measure from teachers or parents (Poskiparta et al. 2003). Previous research suggested that these approaches avoided challenges of reporting young children's self-perception data and were able to provide more objective behavioural measures (Roberts and Sadler 2019). Therefore, this study measured students' motivation via teacher observation by using the items extracted from CIRCLE Progress Monitoring assessments (UTHealth 2018), which is a more comprehensive assessment that emphasizes early literacy skills. The four items selected are assessed with a three-point Likert scale survey (see Appendix I). The Cronbach's coefficient alpha for the scale of motivation to acquire literacy skills is 0.75, which is consistent with the average 0.70 reliability coefficient for studies related to beliefs and value scales reported in a meta-analysis of Cronbach's alpha (Peterson 1994) and other motivation studies in EC contexts (Arens et al. 2011; Patrick, Mantzicopoulos, and Samarapungavan 2009; Roberts and Sadler 2019).

For the first two research questions, this study used Bayesian analysis to interpret the results instead of the *t*-test from the frequentist perspective. The stakeholders such as teachers, parents and developers usually do not fully understand the results of significance tests such as the meaning of $p < 0.05$, which hinders them to interpret the results of AR's impacts on EC. Bayesian analysis, on the other hand, can deliver a more interpretable and insightful evaluation (Kruschke 2013) because it can generate a direct statement of the parameter's probability distribution based on the obtained data. For example, a statement generated from Bayesian analysis can be: 'after the intervention, there is a 95% probability that students' growth rate will be between 65% and 70%'. This statement is more straightforward and informative compared to typical statements generated via frequentists perspective: 'student academic performance has improved significantly after intervention'. The word 'significantly' is part and parcel of statistical jargon that does not reveal practical implications to teachers and parents. Besides, confidence intervals obtained from frequentist approaches are built upon the assumptions created by repeating the experiments an infinite number of times, which only provides limited information to inform the future practice. Therefore, Bayesian analysis offers a better choice for researchers and teachers because the empirical findings are easier for educators to interpret into actionable practices.

For the third research question, six pre- and post-interviews were conducted with teachers from three experimental groups. The constant comparative method

(Gibson and Brown 2009) was applied to analyse the transcripts because this is an inductive approach and the goal of this research question is to discover emergent themes from teachers' interviews. Researchers followed the three-phase analysis process proposed by Wise and Jung (2019) which was used in coding teachers' interviewers after incorporating emerging technologies. In the first phase, researchers worked independently on all transcripts line-by-line to identify potential statements that were relevant to research questions. After labelling each statement, researchers integrated the list of labels into potentially relevant ideas. For the second phase, researchers examined and consolidated ideas by merging or grouping similar ones, and discarded the ones that were insufficiently substantiated by the interviews. The emerging themes that encompass these ideas were discussed and reviewed by researchers, and corresponding definitions and examples were composed and referred. In the last phase, each theme was re-examined by revisiting the transcripts, and their alignments with research questions and connection with other themes were also reconsidered. In total, five themes emerged corresponding to the feedback and reactions teachers had after using AR. Researchers then coded all transcripts following the themes with an inter-rater reliability of 92%.

Results

Research question 1

The proportion of letters that were recognized by each participant was calculated by dividing the number of correct letters students recognized by 26. Thus, the number of 0.7333 in the top of the first column in Table 1 indicates that the average correct rate for the experimental group in the pre-test is 73.33%, which means on average students in this group can recognize 19 letters (26 * 73.33%). Similarly, the number 0.0628 in the last row of the first column indicates the average growth rate is 6.28%, which means, after using the AR application, students were able to recognize two more letters on average (26 * 6.28%). The fourth and fifth column with the wording *HPD* refers to the highest posterior density, the column *HPD 2.5* and *HPD 97.5* indicate the highest posterior density interval (unlike the 95% confidence interval from a frequentist perspective). It was between 2.5th and 97.5th percentiles of parameters' distribution that covers 95% of posterior parameter distribution. For instance, the number 0.7057 and 0.7590 in the top cells of *HPD* columns indicate there is a 95% probability that students' correct rate shown in the pre-test was ranged from 70.57% to 75.90%. The probability of a correct rate lower than 70.57% or above 75.90% compromised the remaining 5% of distribution. Likewise, there was a 95% probability that students' correct rate for the post-test ranged between 77.21% and 82.02%.

Table 1. Comparison of the pre and post rapid letter naming correct rate of the experimental group.

	Mean	Standard deviation	HPD 2.5	HPD 97.5	Rhat
Pre-test correct rate	0.7333	0.0136	0.7057	0.7590	0.9999
Post-test correct rate	0.7961	0.0123	0.7721	0.8202	1.0000
Differences in correct rate	0.0628	0.0183	0.0260	0.0979	1.0000

As presented in Table 1, the number 0.0628 in the last row indicates the average growth rate for students in the experimental group was 6.28%. The results in *HPD* columns revealed that after using the AR application, there was a 95% probability that students' correct rate would grow between 2.60% and 9.79%. These results indicated a growth in students' rapid letter naming rates after using the AR application.

Likewise, as to the growth rate for students in the control group who only used the 2D version of the application (Table 2), the results indicated that there was a 95% probability students had a correct naming rate between 82% and 86.68% in the post-test, compared to 78.44% and 83.54% in the pre-test. However, although their rapid letter naming correct rate had improved, their average growth rate 3.35% was not as high as the experimental group which was 6.28%.

Above all, the results indicated that both groups' rapid letter naming ability increased after using the application, while the students in the experimental group who used the AR version had a greater growth.

Research question 2

Table 3 showed the changes in experimental group students' motivation to acquire literacy skills after the intervention. Students' pre-test motivation score distribution in the 95% interval ranged from 2.02 to 2.33, whereas the post-test ranged from 2.27 to 2.57. The number 0.25 in the last row under the column 'Mean' indicated the average growth was 0.25 points, which is 11.5% in percentage (0.25 divided by the pre-test mean 2.17).

For the students who only used the 2D version of the application (Table 4), their pre-test motivation score distribution in the 95% interval ranged from 1.93 to 2.29, whereas the post-test ranged from 2.16 to 2.52. The average growth reached 0.23 points, which is 10.9% (0.23 divided by the pre-test mean 2.11), and this rate was similar to the growth rate of the experimental group (11.5%).

In all, the results indicate both 2D and AR versions of the application have improved student motivation ratings, although the experimental group had a slightly larger change than the control group.

Table 2. Comparison of the pre and post rapid letter naming correct rate of the control group.

	Mean	Standard deviation	HPD 2.5	HPD 97.5	Rhat
Pre-test correct rate	0.8098	0.0131	0.7844	0.8354	0.9999
Post-test correct rate	0.8434	0.0120	0.8200	0.8669	0.9999
Differences in correct rate	0.0335	0.0178	−0.0016	0.0682	0.9999

Table 3. Comparison of the pre and post motivation score of the experimental group.

	Mean	Standard deviation	HPD 2.5	HPD 97.5	Rhat
Pre-test mean	2.17	0.08	2.02	2.33	0.9999
Post-test mean	2.42	0.08	2.27	2.57	1.0002
Difference of mean	0.25	0.11	0.04	0.48	1.0000

Table 4. Comparison of the pre and post motivation score of the control group.

	Mean	Standard deviation	HPD 2.5	HPD 97.5	Rhat
Pre-test mean	2.11	0.09	1.93	2.29	1.0001
Post-test mean	2.35	0.09	2.16	2.52	0.9999
Difference of mean	0.23	0.13	−0.01	0.50	1.0000

Table 5. Themes emerged from teacher interviews.

Theme	Definition	Example
Incorporating approaches	How teachers incorporated AR sets in their daily practices, how they set up the classroom	So we had the iPad in our classroom and it was set up in a centre near our library centre
Student learning growth	The students' learning growth after using the AR set, including their literacy growth and motivation growth	They are realising they can sound out letters to make words a little more now than before
New dynamic brought to the classroom	Other changes, both positive and negative, noticed by teachers other than learning growth	The children get to try and use several senses at one time which can be another developmental advantage
Teachers' attitude changes	Changes in opinion regarding incorporating AR or similar cutting-edge technologies in elementary classrooms	Pre-interview: I am curious to know what... how they might interact and how what they would think about it Post-interview: The children seemed to be very interested in this app throughout the process but at first, it was challenging
Implications for future uses	Teachers' suggestions or feedback to share with future AR or similar cutting-edge technologies usage	It can definitely be helpful with children at the beginning of each school year to help strengthen their letter recognition and matching sounds

Research question 3

Five themes emerged from the six transcripts by three teachers in experimental classes, they revealed ways in which teachers, students and classroom dynamics change with an AR centre (see Table 5).

Incorporating approaches (n = 10) refers to how teachers incorporated AR sets in their daily lesson plans and how they set up the classroom to cope with the logistical needs of implementing AR; all three teachers mentioned that they incorporated AR as one of the learning centres in their class. *Student learning growth* (n = 17) was a theme that permeated all interviews and resonated with quantitative results; students had improved rapid letter naming rates and motivation. One teacher explained 'They have been more excited about reading. A little boy in our class who was always kind of stand-offish. This made it come to life for him more than anything else we could design in our classroom'. *New dynamics brought to the classroom* (n = 21) are changes observed outside of improvement in student literacy or motivation. For example, a teacher mentioned that '...they were able to engage with something that wasn't a teacher, that wasn't another person, that was the letter itself and they got to mess around with it in a different way than they ever have before', and 'The children get to try and use several senses at one time which can be another developmental advantage'. *Teachers' attitude changes* (n = 9) were less common than any other themes, likely because AR was a recognizable technology to all teachers, but they had not taught using it. *Implications for future uses* (n = 11) refers to teacher suggestions or feedback gained during the process. In general, teachers brought up their concerns and ideas for educators who were contemplating to use AR in the future. One teacher found it as a good tool because children can be able to 'strengthen their letter recognition and matching sounds'. Moreover, teachers also provided their feedback about the challenges of figuring out how EC students can best hold and manage the device while also taking advantage of interactive features.

Discussion

To extend the research on AR's impact in EC contexts, this study focused on rapid letter naming and students' motivation to acquire literacy skills. By comparing results of students in control groups who only accessed the 2D version of the application to those of the experimental groups who had access to AR features, the results revealed meaningful implications about AR's impact as an educational tool in EC. Besides, interviews with the teachers also shed light on teacher feedback and suggestions to incorporate AR into EC contexts.

Rapid letter naming skills

For rapid letter naming skills, students who used the AR version of the application had lager growths compared to students who only used the 2D version, indicating AR did help students to recognize more letters. A possible explanation can be attributed to the different interaction styles of the two groups when engaging with the application.

Because the classroom environments and activity patterns are the same for both conditions, it is possible to infer that the main factor that contributed to the different growth rate between the two groups is the different interaction style when engaging with the AR or 2D features. In control groups, after students enter the application, the main interactions between students and the application are watching the animation and tapping the left or right arrow to proceed (see Figure 3 and Figure 4). Whereas in the experimental groups, a series of manipulations are required for students to trigger the animation and go through the book. For instance, students needed to align the picture book and device camera to activate interactions, then tap each static letter to trigger the animations associated with each individual letter, and turn pages in the physical book to go to the next letter, then they would repeat all these interactions until they reached the end of the book (see Figure 5). Based on a previous study by Cheng and Tsai (2014), the behaviours associated with AR such as pointing, responding and turning can endow children with a sense of control, which fosters a positive attitude towards the learning activities. This positive experience might potentially increase students' learning efficiency about letters in the AR group.

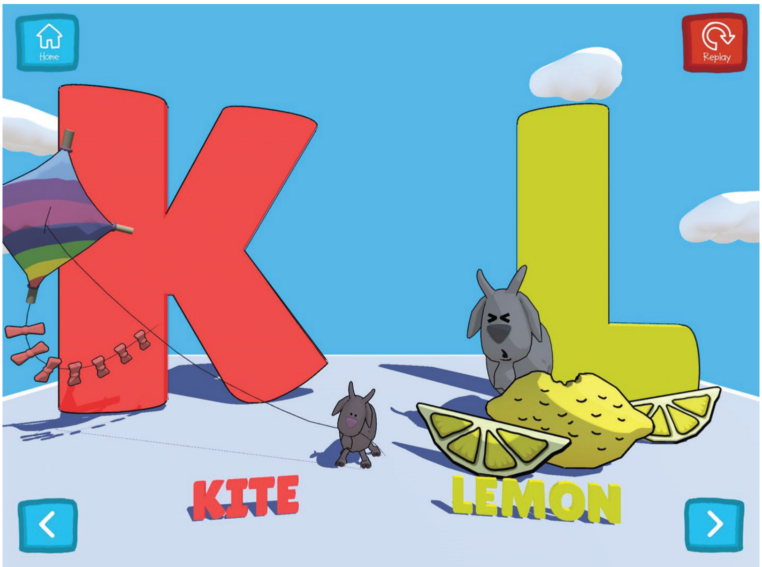

Figure 3. The interface of 2D version and two arrows at the bottom to change pages.

Figure 4. Students' interaction in the control group.

Moreover, previous studies (Ehri 2005; Roberts, Vadasy, and Sanders 2019) also indicated when letter names were systematically corresponding to the written forms, the connections can be easily stored into long-term memory. In this case, compared to the 2D version, the AR mode not only associated letter names with their written forms systematically but also involved animations and motor

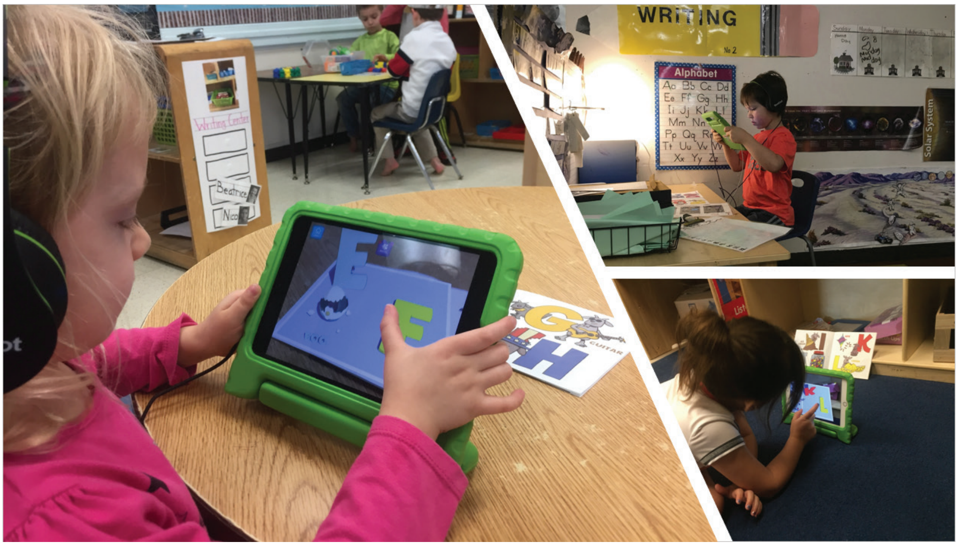

Figure 5. Students' interaction in the experimental group.

movements, thus the connections could be more efficiently formed for children and make their recognition process smoother.

This finding is further supported by a more detailed analysis of students' learning gains on each letter (Figure 6). The x-axis represents the total number of students who named the letter correctly, and each count represents a correct answer by one student. The bars from pre-test and post-test have been placed overlapping in the same graph to clearly show when there was an increase (yellow) or decrease (blue) in the number of students who rapidly named the letter correctly. For example, for the letter 'X' in the bottom graph, only 32 students have correctly named the letter in the pre-test, while 36 students named the letter correctly in the post-test. Overall, there is a larger increase in rapid letter naming ability among the experimental group because more letters were marked with orange, which indicates growth; whereas the control group showed more letters were recognized fewer times in the post-test (blue). Another noteworthy finding is, for both groups, 'I' is the most missed letter. In a recent study, Treiman, Stothard, and Snowling (2019) proposed a visual confusability hypothesis inferring that letters with similar appearance would cause children's confusion in the letter naming process. In this context, children might confuse the letter 'I' with a lower-case 'L' that explains why 'I' was missed the most in this study. This finding further calls for more careful letter graphic design in AR application.

In sum, the results have shown that AR is capable and effective in enhancing children's rapid letter naming skills. The finding indicates AR can play a positive role in empowering EC literacy education, and it also extended the previous literature by proving that AR's affordances in EC education are beyond STEM-related content areas.

Motivation to acquire literacy skills

The results of motivation showed students in both groups have similar growth rates; the AR group (11.5%) had a slightly higher rate than the 2D group (10.9%). It indicates

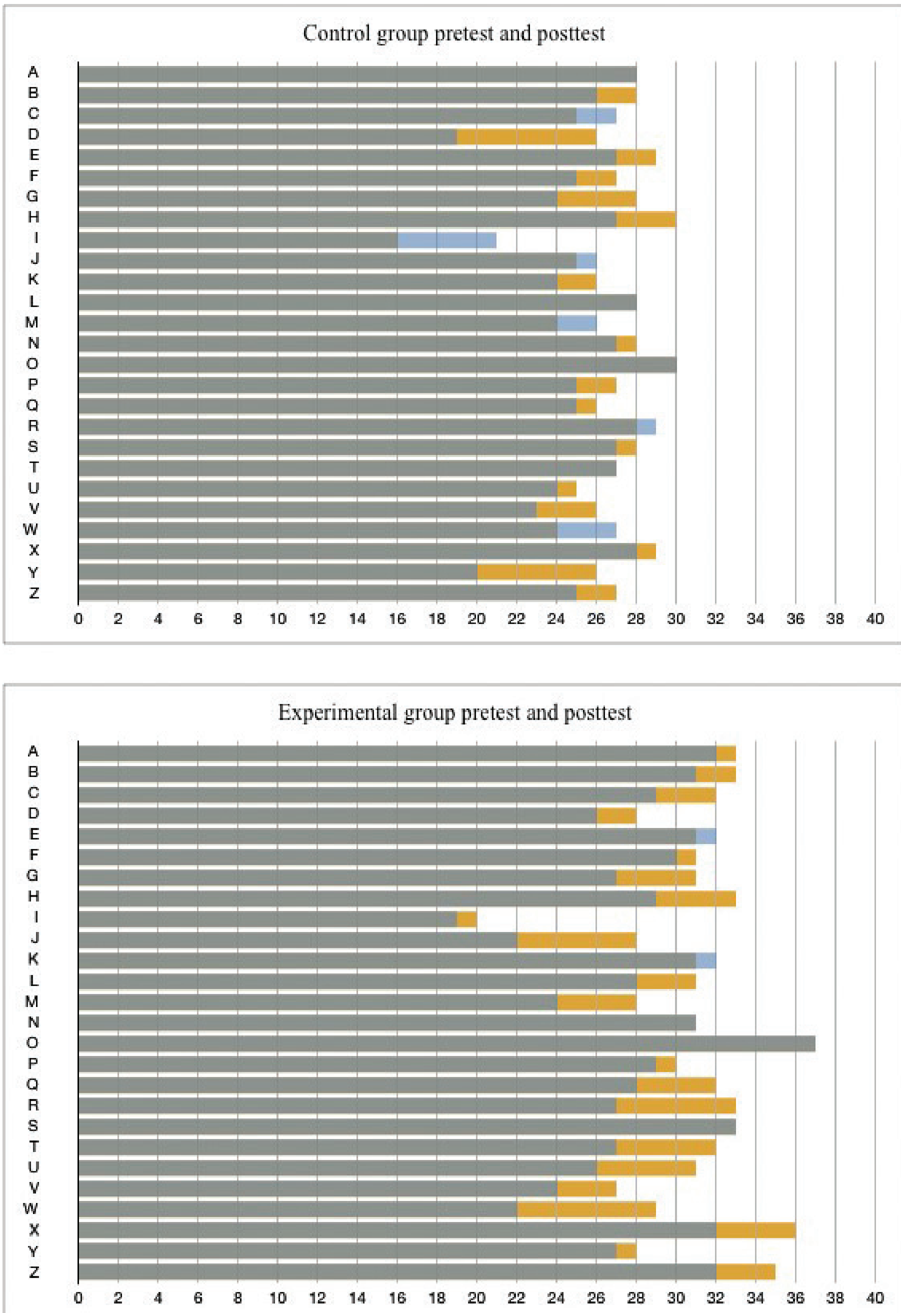

Figure 6. Comparison of each letter for control and experimental groups.

the AR and 2D features of the application have similar effects on students' motivation growth. Among the studies that focused on motivation, Wigfried and Guthrie explained intrinsic motivation through three aspects: curiosity, choice and preference for challenge (as cited in Ciampa 2016, p. 669). In this study, the features of this application and the learning centres style engaged all three of these aspects: (1) both 2D and AR features provided vivid interactive experiences that are attractive to students and also different from other centres; (2) children had the choice of how often and when to visit the learner-centred activity and (3) activities provided manageable challenges for children when interacting with the application. Thus, centred around student choice and autonomy, the activity provided concrete ways for the three aspects of intrinsic motivation to be tapped into, which could explain the growth of motivation in both AR and 2D conditions.

Another possible explanation for the growth in motivation among both groups could be the restriction of didactic instruction. The didactic instruction refers to a teacher-centred instructional approach that focuses on direct knowledge-transmission (Hickey, Moore, and Pellegrino 2001), which is contrary to a constructivist or student-centred instructional approach (Nie and Lau 2010). Prior studies have found a negative correlation between didactic instruction and children's motivation (Stipek et al. 1995, 1998). The picture book application granted students enough autonomy to explore the content on their own and at their own pace. For instance, when interacting with the application, instead of following teacher pacing, children were able to go back and forth and manipulate the content at their own pace. In other words, this activity fostered a student-centred literacy learning environment that broke away from the restrictive nature of didactic instruction, thus cultivated their motivation in learning literacy.

In summary, the superimposed 3D graphics and animations generated by the AR feature is effective but is not the only factor that contributed to the motivational growths. It is more likely the involvement of high levels of autonomy and choices that were delivered by the application led to higher motivation.

Teacher feedback

All teachers implemented AR activity as an optional learning centre, which resonated with the findings from previous studies that learning centre is a common strategy in EC that can be used to investigate the effects of cutting-edge technologies (Jackman, Beaver, and Wyatt 2014; Metin 2017). Its advantage is that it does not require much training to set up a new centre, and teacher's main role is to monitor students as they normally do (Kostelnik et al. 2015; Pellegrino 2007). As teachers in the study indicated, implementation did not interfere with routine learning activities and children could 'go and interact with the app as they desired, as they wanted' the same way they interacted with other centres. Thus, findings from teachers' interviews confirmed that when incorporating newly emerged educational technologies into classrooms that serve young children, the learning centre is an appropriate strategy.

Similar to a study by Flewitt, Messer, and Kucirkova (2015), teachers in this study held positive views about AR. All teachers provided evidence or anecdotes in terms of students' growth in literacy and motivation. For instance, a teacher mentioned: 'a little boy who was having a hard time with letter recognition……(now) He was able to do some really awesome work. Again, I think this helped us engage him in a way we weren't able to before'. In our study, teachers' attitude changes towards AR were not very stark and involved more of a journey from curiosity about AR to confidence. One teacher reflected that 'it was really great cause I feel like this day and age, this is what we're coming to… so I think it definitely would benefit to be in a classroom'.

The interviews also revealed teachers' concerns over limiting screen time, for example, as one teacher mentioned, 'I think if it comes to it, it definitely needs to be monitored'. This indicates the importance of using timing devices when involving AR in the classroom. Other statements implied there is a need for making sure children know how to hold and manipulate the device. 'The challenge was trying to figure out the best way to hold the tablet to get a good visual of the picture in the book and then also touching the screen to get the auditory effect'. As to learning efficiency, one teacher considered AR 'can definitely be helpful with children at the beginning of each school year to help strengthen their letter recognition and matching sounds'. While another teacher even suggested that in the future 'we can use these skills they learn or strengthen to plan lessons and set personal goals for each child and class in this area of development', which indicating that AR can be a tool to create more personalized learning. Furthermore, as revealed by observations and interviews, AR also served as a space where children could 'learn to take turns', a social skill teachers found very valuable among this age group. Besides, unlike the teachers in Uygur, Yelken, and Akay's study (2018), in which half of them were unfamiliar with AR, all of the teachers in our study were familiar with a type of AR technology which implies that teacher professional development needs are changing.

In summary, teacher statements revealed that in the future, AR should be implemented as a timed learning centre that children are able to participate in, and it can provide teachers an opportunity to create personalized learning. If the device to student ratio allows, it also gives space for practicing social skills such as sharing and taking turns. Furthermore, interviews also showed that teachers in this study felt more confident using AR in the literacy classroom after witnessing their own students experience it.

Implications

In contrast to previous research, our study addressed concerns regarding time limits and provided an example of how future studies could be conducted. Particularly, this study emphasizes that the methodology of an AR study should include pragmatic responses to stakeholders' concerns such as minimizing exposure. For example, the parents, administrators and teachers participating in this study found limiting use of digital devices to be extremely important for their classrooms. Therefore, in this context, research involving AR applications that require the usage of tablets should have a system in place that can help monitoring excessive usage by notifying the instructor and/or learner. In addition, studies that focus on EC need to ensure that the manipulation should be easy enough for children to accomplish. In the case of this study, manipulation was easily done by pointing the device camera towards a page in the book. Investigations exploring new technologies among EC classrooms must be designed with easy manoeuvrability in mind, and only then can researchers expect a study to be well-designed for testing the effect of new technologies such as AR on EC learning goals.

Limitations

This study measured the rapid letter naming ability and motivation of students by using class averaged data, which means it is difficult to know AR's individualized effects on each student. Future studies should be conducted focussing on AR's effects on individual students who have different demographic backgrounds and learning preferences. The children that participated in this study turned out to have a higher rapid letter naming ability than their teachers expected and thus left smaller rooms for growth from pre-test to post-test on rapid letter naming skills. Further studies should be conducted with larger groups of students across a diverse set of contexts and prior knowledge. Besides, this study used teacher's observations to measure students' motivation. Future studies that incorporate other approaches to collect motivational data are suggested.

Conclusion

By incorporating an AR application into pre-kindergarten classrooms, this study presents the beneficial nature of timed AR tablet activities on improving rapid letter naming skills in EC. The findings also revealed both the AR and 2D versions of the same application enhanced children's motivation to acquire literacy skills. Moreover, the results about the differences in probability of students' growth under AR and 2D conditions provided future educators and researchers with detailed and interpretable implications. Besides, this study also revealed that using the learning centre activity strategy can be an approach for pre-kindergarten teachers and researchers to incorporate other types of educational technologies that emerge in the future.

Reference

Akçayır, M. & Akçayır, G. (2017) 'Advantages and challenges associated with augmented reality for education: a systematic review of the literature'. *Educational Research Review*, vol. 20, no. 1, pp. 1–11. doi: 10.1016/j.edurev.2016.11.002

Arens, A. K., et al., (2011) 'The twofold multidimensionality of academic self-concept: domain specificity and separation between competence and affect components', *Journal of Educational Psychology*, vol. 103, no. 4, p. 970. doi: 10.1037/a0025047

Azuma, R., et al., (2001) 'Recent advances in augmented reality', *IEEE Computer Graphics and Applications*, vol. 21, no. 6, pp. 34–47. doi: 10.1109/38.963459

Berhenke, A., et al., (2011) 'Observed emotional and behavioral indicators of motivation predict school readiness in head start graduates', *Early Childhood Research Quarterly*, vol. 26, no. 4, pp. 430–441. doi: 10.1016/j.ecresq.2011.04.001

Chang, F. & Burns, B. M. (2005) 'Attention in preschoolers: associations with effortful control and motivation', *Child Development*, vol. 76, no. 1, pp. 247–263. doi: 10.1111/j.1467-8624.2005.00842.x

Chapman, J. W. & Tunmer, W. E. (1995) 'Development of young children's reading self-concepts: an examination of emerging subcomponents and their relationship with reading achievement', *Journal of Educational Psychology*, vol. 87, no. 1, p. 154. doi: 10.1037/0022-0663.87.1.154

Cheng, K. H. & Tsai, C. C. (2014) 'Children and parents' reading of an augmented reality picture book: analyses of behavioral patterns and cognitive attainment', *Computers & Education*, vol. 72, pp. 302–312. doi: 10.1016/j.compedu.2013.12.003

Ciampa, K. (2016) 'Motivating grade 1 children to read: exploring the role of choice, curiosity, and challenge in mobile ebooks', *Reading Psychology*, vol. 37, no. 5, pp. 665–705. doi: 10.1080/02702711.2015.1105337

Cornwall, A. (1992) 'The relationship of phonological awareness, rapid naming, and verbal memory to severe reading and spelling disability', *Journal of Learning Disabilities*, vol. 25, no. 8, pp. 532–538. doi: 10.1177/002221949202500808 disruptED. (2020, June) 'We bring learning to life! [online]', Available at: https://disruptedx.com

Ehri, L.C. (2005) 'Learning to read words: theory, findings, and issues', *Scientific Studies of Reading*, vol. 9, no. 2, pp. 167–188. doi: 10.1207/s1532799xssr0902_4

Gibson, W. & Brown, A. (2009) *Working with Qualitative Data*, Sage, Los Angeles, CA. doi: 10.4135/9780857029041

Flewitt, R., Messer, D. & Kucirkova, N. (2015) 'New directions for early literacy in a digital age: the iPad', *Journal of Early Childhood Literacy*, vol. 15, no. 3, pp. 298–310. doi: 10.1177/1468798414533560

Gecu-Parmaksiz, Z. & Delialioğlu, Ö. (2018) 'The effect of augmented reality activities on improving preschool children's spatial skills', *Interactive Learning Environments*, vol. 28, no. 7, pp. 1–14. doi: 10.1080/10494820.2018.1546747

Gudoniene, D. & Rutkauskiene, D. (2019) 'Virtual and augmented reality in education', *Baltic Journal of Modern Computing*, vol. 7, no. 2, pp. 293–300. doi: 10.22364/bjmc.2019.7.2.07

Hmelo-Silver, C. E. (2003) *The Constructivist Teacher: Facilitating Problem Based Learning*, Paper presented at the American Educational Research Association Annual Meeting, Chicago, IL [online]. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.112.4497&rep=rep1&type=pdf

Hickey, D. T., Moore, A. L. & Pellegrino, J. W. (2001) 'The motivational and academic consequences of elementary mathematics environments: do constructivist innovations and reforms make a difference?', *American Educational Research Journal*, vol. 38, no. 3, pp. 611–652. doi: 10.3102/00028312038003611

Ho, S. C., et al., (2017) 'To activate English learning: listen and speak in real life context with an AR featured u-learning system', *Journal of Educational Technology & Society*, vol. 20, no. 2, pp. 176–187.

Hornecker, E. & Dünser, A. (2009) 'Of pages and paddles: children's expectations and mistaken interactions with physical–digital tools', *Interacting with Computers*, vol. 21, nos. 1–2, pp. 95–107. doi: 10.1016/j.intcom.2008.10.007

Ibáñez, M. B. & Delgado-Kloos, C. (2018) 'Augmented reality for STEM learning: a systematic review', *Computers & Education*, vol. 123, pp. 109–123. doi: 10.1016/j.compedu.2018.05.002

Jackman, H., Beaver, N. & Wyatt, S. (2014) *Early Education Curriculum: A Child's Connection to the World*, 6th edn, Cengage Learning, Stanford, CA.

Kaya, O. S. & Bicen, H. (2019) 'Study of augmented reality applications use in education and its effect on the academic performance', *International Journal of Distance Education Technologies*, vol. 17, no. 3, pp. 25–36. doi: 10.4018/IJDET.2019070102

Kostelnik, M. J., et al., (2015) *Developmentally Appropriate Curriculum: Best Practices in Early Childhood Education*, 6th edn, Prentice Hall, Upper Saddle River, NJ.

Kruschke, J. K. (2013) 'Bayesian estimation supersedes the *t* test', *Journal of Experimental Psychology: General*, vol. 142, no. 2, p. 573. doi: 10.1037/a0029146

Lorusso, M., et al., (2018) 'Giok the alien: an AR-based integrated system for the empowerment of problem-solving, pragmatic, and social skills in pre-school children', *Sensors*, vol. 18, no. 7, pp. 23–68. doi: 10.3390/s18072368

Metin, Ş. (2017) 'Investigation of the practices in learning centers of pre-school education institutes', *Turkish Journal of Education*, vol. 6, no. 1, pp. 1–16. doi: 10.19128/turje.267357

Nie, Y. & Lau, S. (2010) 'Differential relations of constructivist and didactic instruction to students' cognition, motivation, and achievement', *Learning and Instruction*, vol. 20, no. 5, pp. 411–423. doi: 10.1016/j.learninstruc.2009.04.002

Patrick, H., Mantzicopoulos, P. & Samarapungavan, A. (2009) 'Motivation for learning science in kindergarten: is there a gender gap and does integrated inquiry and literacy instruction make a difference', *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, vol. 46, no. 2, pp. 166–191. doi: 10.1002/tea.20276

Pellegrino, A. M. (2007) *How Can Learning Centers Be Used to Support Classroom Instruction and Promote Critical Thinking in a Kindergarten Classroom?* Unpublished Master's Thesis, Rowan University, Glassboro, NJ.

Peterson, R. A. (1994) 'A meta-analysis of Cronbach's coefficient alpha', *Journal of Consumer Research*, vol. 21, no. 2, pp. 381–391. doi: 10.1086/209405

Poskiparta, E., et al., (2003) 'Motivational-emotional vulnerability and difficulties in learning to read and spell', *British Journal of Educational Psychology*, vol. 73, no. 2, pp. 187–206. doi: 10.1348/00070990360626930

Roberts, T. A. & Sadler, C. D. (2019) 'Letter sound characters and imaginary narratives: can they enhance motivation and letter sound learning?', *Early Childhood Research Quarterly*, vol. 46, pp. 97–111. doi: 10.1016/j.ecresq.2018.04.002

Roberts, T. A., Vadasy, P. F. & Sanders, E. A. (2019) 'Preschoolers' alphabet learning: cognitive, teaching sequence, and English proficiency influences', *Reading Research Quarterly*, vol. 54, no. 3, pp. 413–437. doi: 10.1002/rrq.242

Sahin, N. & Ozcan, M. F. (2019) 'Effects of augmented reality in teaching old Turkish language mementoes on student achievement and motivation', *Contemporary Educational Technology*, vol. 10, no. 2, pp. 198–213. doi: 10.30935/cet.554501

Sirakaya, M. & Alsancak Sirakaya, D. (2018) 'Trends in educational augmented reality studies: a systematic review', *Malaysian Online Journal of Educational Technology*, vol. 6, no. 2, pp. 60–74. doi: 10.17220/mojet.2018.02.005

Sommerauer, P. & Müller, O. (2014) 'Augmented reality in informal learning environments: a field experiment in a mathematics exhibition', *Computers & Education*, vol. 79, pp. 59–68. doi: 10.1016/j.compedu.2014.07.013

Stipek, D., et al., (1995) 'Effects of different instructional approaches on young children's achievement and motivation', *Child Development*, vol. 66, no. 1, pp. 209–223. doi: 10.2307/1131201

Stipek, D. J., et al., (1998) 'Good beginnings: what difference does the program make in preparing young children for school?', *Journal of Applied Developmental Psychology*, vol. 19, no. 1, pp. 41–66. doi: 10.1016/S0193-3973(99)80027-6

Stotz, M. & Columba, L. (2018) 'Using augmented reality to teach subitizing with preschool students', *Journal of Interactive Learning Research*, vol. 29, no. 4, pp. 545–577.

Treiman, R., Stothard, S. E. & Snowling, M. J. (2019) 'Knowledge of letter sounds in children from England', *Applied Psycholinguistics*, vol. 40, no. 5, pp. 1299–1311. doi: 10.1017/S0142716419000274

Tynjala, P. (1999) 'Towards expert knowledge? A comparison between a constructivist and a traditional learning environment in the university', *International Journal of Educational Research*, vol. 31, no. 5, pp. 357–442. doi: 10.1016/S0883-0355(99)00012-9

UTHealth. (2018, May) *CIRCLE Progress Monitoring System (PreK)* [online]. Available at: https://cliengage.org/public/tools/assessment/circle-progress-monitoring/

Uygur, M., Yelken, T. Y. & Akay, C. (2018) 'Analyzing the views of pre-service teachers on the use of augmented reality applications in education', *European Journal of Educational Research*, vol. 7, no. 4, pp. 849–860. doi: 10.12973/eu-jer.7.4.849

Wang, L., Lee, H. & Ju, D. Y. (2019) 'Impact of digital content on young children's reading interest and concentration for books', *Behavior & Information Technology*, vol. 31, no. 1, pp. 1–8. doi: 10.1080/0144929X.2018.1502807

Wei, X., et al., (2015) 'Teaching based on augmented reality for a technical creative design course', *Computers & Education*, vol. 81, pp. 221–234. doi: 10.1016/j.compedu.2014.10.017

Wilson, K. M. & Trainin, G. (2007) 'First-grade students' motivation and achievement for reading, writing, and spelling', *Reading Psychology*, vol. 28, no. 3, pp. 257–282. doi: 10.1080/02702710601186464

Wise, A. F. & Jung, Y. (2019) 'Teaching with analytics: towards a situated model of instructional decision-making', *Journal of Learning Analytics*, vol. 6, no. 2, pp. 53–69. doi: 10.18608/jla.2019.62.4

Yilmaz, R. M. (2016) 'Educational magic toys developed with augmented reality technology for early childhood education', *Computers in Human Behavior*, vol. 54, pp. 240–248. doi: 10.1016/j.chb.2015.07.040
Yilmaz, R. M., Kucuk, S. & Goktas, Y. (2017) 'Are augmented reality picture books magic or real for preschool children aged five to six?', *British Journal of Educational Technology*, vol. 48, no. 3, pp. 824–841. doi: 10.1111/bjet.12452
Yuliono, T. & Rintayati, P. (2018) 'The promising roles of augmented reality in educational setting: a review of the literature', *International Journal of Educational Methodology*, vol. 4, no. 3, pp. 125–132. doi: 10.12973/ijem.4.3.125

Appendix I

Assessment of motivation to read.

Motivation to read			
Please rate the following statements	1 – Rarely	2 – Sometimes	3 – Consistently
Child shows interest in reading by self-selecting books during centres or free choice periods			
Child shows enthusiasm and engagement during shared or interactive reading activities			
Child asks to be read to (including books and/or print in the environment)			
Child asks the meaning of text (including books and/or print in the environment)			