The Influence of using Augmented Reality on Textbook Support for Learners of Different Learning Styles

Jia Zhang[1]
Graduate Institute of Information and Computer Education, National Taiwan Normal University, Taiwan

Amy Ogan[2]
Human-Computer Interaction Institute Carnegie Mellon University, US

Tzu-Chien Liu[3]
Department of Educational Psychology and Counseling National Taiwan Normal University, Taiwan

Yao-Ting Sung[4]
Department of Educational Psychology and Counseling National Taiwan Normal University, Taiwan

Kuo-En Chang[5]
Graduate Institute of Information and Computer Education, National Taiwan Normal University, Taiwan

ABSTRACT
It has been shown in numerous studies that the application of Augmented Reality (AR) to teaching and learning is beneficial, but determining the reasons behind its effectiveness, and in particular the characteristics of students for whom an AR is best suited, can bring forth new opportunities to integrate adaptive instruction and AR in the future. Through a quasi-experimental research design, our study recruited 66 participants in an 8-week long AR-assisted learning activity, and lag sequential analysis was used to analyze participants' behavior in an AR learning environment. We found that AR was more effective in enhancing the learning gains in elementary school science of learners who prefer a Kinesthetic approach to learning. We hypothesize that these effects are due to the increase in opportunity for hands-on activities, effectively increasing learners' concentration and passion for learning.

Keywords：Augmented Reality, Computer-assisted instruction, K-12 education

Index Terms：H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; K.3.1 [Computer and Education]: Computer Uses in Education—Computer-assisted instruction (CAI)

1. INTRODUCTION

In recent years, Augmented Reality (AR) has become a much-discussed research topic, and has been widely applied in various contexts including those of instruction and learning [1][2][3][4][5]. A literature review shows that research on the use of AR techniques to improve or assist instruction and learning has been increasing in the past few years. Based on statistics from the SSCI and ERIC databases, between 1994 and 2015, a total of 1,748 articles focusing on the development and application of AR were published, demonstrating an annual increase in research in this area. Internationally, many scholars also argue that AR is a learning tool with a totally new format, with much room for development in the future as the relevant technology progresses [6].

From the point of view of technology-assisted learning, AR also brings about a new opportunity to adapt different learning tools to the unique characteristics of different types of learners [7][8][9].

[1]zhangjiatw@gmail.com
[2]aeo@cs.cmu.edu
[3]tzuchien@ntnu.edu.tw
[4]sungtc@ntnu.edu.tw
Corresponding author: [5]kchang@ntnu.edu.tw

Continued research has been conducted in previous decades concerning differences in individual learning style, and these differences are one factor that accounts for the different efficacies of various instruction strategies on individual learners [10][11]. With the development of different instructional strategies and particularly as technology-assisted instruction is introduced in the classroom, the goal is to enhance efficacy for more learners. This should not be limited to producing effects on a specific group of learners or on only high-achieving learners, but rather supporting learners with the most effective tool for their needs. These similar ideas have been continuously proposed [12][13].

Past studies in AR have concentrated on its use during instruction, often comparing learning efficacy and learning motivation among learners across different grades and subjects [15][16][17][18][19][20][21][22][23][24][25][26]. For example, AR-aided instruction increased learning efficacy and motivation in various topics such as electromagnetism[16] ,natural science[20][22] ,physics[24] ,guidance of heritage[25] and painting appreciation[26]. This researches has included K-12 students [24], college students [25][26] and others, and different environments. According to the aforementioned literature, it has been shown that from a general perspective, AR aids learning. However, the specific causes of improvement due to the use of AR have not yet become clear, and in particular, none of these studies have explained the effects of AR on learning efficacy with respect to different preferences for interacting with and viewing learning materials. When using AR, learners interact with the material in a variety of ways that may differ from the traditional classroom [15][16][18][19][25][26]. For example, in a case of using AR to support astronomical observation, learner held the device at specific angles to view events in the sky and the AR user interface showed augmented information on the camera view [16]. Therefore, it is reasonable to hypothesize that augmented reality may be particularly suitable for learners who have strong preferences for visual or kinesthetic interactions.

In 1984, Reid proposed a classification of learning styles, where some of the learning styles identified consisted of learning through visual images and hands-on activities [14]; this was similar to the view of Mayer (1987) in his research [12]. This line of research suggests that the interaction between learners' preferences or styles and the use of aligned learning methods, strategies or tools, might improve some learners' efficacy in typical instruction environments. However, one prevailing paradigm states that learning styles are obtained from learners' experiences in the learning environment instead of being an innate property of an individual. Malcom (1981) mentioned that learning style is born of a learner's experience [45]. Keefe (1979, 1982) also proposed that learning styles are a sign of learner's performance in the learning environment seen through the interaction between the learner and learning material [46][47]. According to the aforementioned work, learning methods,

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strategies or tools may enhance the student's learning when they match the category of preexisting interaction preferences; alternatively, learning styles may be changed by the experience with learning methods, strategies or tools (environment). There are clearly possibilities to further develop a method, strategy and tools that can support corresponding learner types, as well as simultaneously achieving good learning efficacy.

It is worth researching which types of instructional content are appropriate, and which strategies and learning resources should be adopted by investigating the different ways in which learners interact with AR based on their preferences [27][28], and attempting to integrate adaptive learning into the technical framework of AR. While there is some ongoing research in this area [29][30], all note that this is an integration between technology and learning strategy [31], which could greatly enhance the potential of AR in instruction and learning.

Therefore, this study makes use of system log analyses of behavior, learning assessments, as well as self-report surveys to understand the efficacy of AR-assisted textbook learning for learners with different learning styles, and to understand their inherent behavioral differences. This information could provide answers to the adaptability of AR to specific learning styles, which could serve as a criterion for designing AR-assisted instruction and learning in the future. The present study deployed an AR-reading assistant tool in upper elementary school science classes. A number of specific instruction units were chosen and an 8-week long test was conducted with the accompanying textbooks. The following two goals comprised the specific aims of our research:

(1) With a quasi-experimental study, we compare whether there are differences in learning achievement in science, by comparing the use of an AR-reading assistant tool by learners of different learning styles.

(2) With the use of lag sequential analysis, we analyze the operation behavior with an AR-reading assistant tool, and the interactions with the tool among learners with different learning styles.

2. Methodology

2.1 Participants

A total of 66 students participated from three classes of one upper elementary school in Taiwan, which is a middle size public school in the urban environment. All students were randomly assigned to the class by government policy. For this study, we select three classes, Class A, Class B, and Class C (22, 21, and 23 participants respectively). Class A and Class C were from grade 5, and Class B was from grade 6; all students were 11 or 12 years old. The participants all had the same instructor, an elementary school science teacher with 20 years of teaching experience in the subject. Moreover, all participants had very similar learning achievement in science prior to the experiment. According to their past examination results, there was no significant difference between the academic performance of the three classes ($F(2,63)=.369$, $p=.693$). However, the pre-test on the targeted course, which was administered to the three classes before the present study, revealed significant differences between the classes with regard to their background knowledge of the targeted course ($F(2,63)=5.056$, $p=.009$). According to the instructor's feedback, some of the tested learners received outside tutoring, and the distribution of tutorial class attendance was uneven, which might account for their unequal background knowledge. All participants and instructor were the same groups as in previously reported research in Zhang, et al. (2015). This study obtained new behavioral data from the system logs, and also utilized a pre-test and self-report VAK instrument [32].

By using the VAK instrument (VAK learning styles self-assessment questionnaire) [32], two classes of participants, Class A and Class B, were categorized into three different groups, Visual, Auditory, and Kinesthetic, based on the items for which they indicated the most preference. Among all participants, 17 students were categorized in the Visual preference, 9 students in the Auditory preference, and 17 students preferred the Kinesthetic approach. Miller (2001) and Hodson and Willis (1999) noted in their research that approximately 29% of elementary school students are Visual learners, 34% are Auditory learners, and 37% are Kinesthetic learners [33][34]. These proportions of distribution differed slightly from our study, and possible factors affecting the difference include ethnicity, and the cultural and regional backgrounds of the participants. Class C was the background control group, for whom no mobile devices were used for teaching, so the VAK instrument was not administered.

The three different types of learning style were used for group considerations, and there were no significant differences in their school examination results in the subject of science ($F(2,40)=1.713$, $p=.193$). However, the average score of Auditory learners was 92.11 ($SD=3.44$), which was higher than the Visual learners ($M=88.59$, $SD=5.821$) and Kinesthetic learners ($M=87.18$, $SD=8.087$). Moreover, regarding the pre-test we administered in the targeted experimental unit of instruction, there were already significant differences between the three different types of learner in terms of their prior knowledge ($F(2,40)=3.262$, $p=.049$). Pre-test scores of Auditory learners averaged 80.33 ($SD=7.81$), which was higher than the Visual learners ($M=75.88$, $SD=10.130$) and Kinesthetic learners ($M=68.53$, $SD=12.564$).

2.2 System

The system adopted by the present study, i.e., the AR-reading assistant tool, was developed by Zhang, et al. (2015) [15], in combination with matching authoring tools, so that the instructor could edit supplementary teaching materials for the course on this specific tool platform, and identifiable marks could be made on the textbooks (such as pictures of text paragraphs). Simply by using the camera of the mobile device, the supplementary teaching materials could be presented to learners in the format of AR of a specific paragraph of the textbooks during lessons (figure 1). Based on an identical technique used in previous practice [25][26], in order to ensure the stable presentation to learners of supplementary teaching materials in the form of augmented information, once the system had generated augmented information, the screen would lock. Only when a learner pressed the backward button would the system return to the detecting state of AR.

Figure 1.The screenshot of AR system

The system's AR technology came from the Simply Viewport Strategy System (SVSS) complete view augmented engine developed by Zhang, Hou, and Chang (2012) [35]. The engine was mainly designed to relieve the load on the mobile device produced by algorithms, thus reducing the intervention of technological factors in instruction. SVSS technologies have been applied in many indoor and outdoor learning environments, and their stability and quality have been demonstrated [15][25][26]. This engine can use the original images to mark specific pictures or text paragraphs accurately without additional marking, and no writing of

Table 1 System code and changes in coding

System Code	Coding	Action	Behaviors
{0}	O	The AR-reading assistant tool was turned on.	System operation
{L}	L	The learner logged into the account.	System operation
{I}	I	Welcome page of the course.	System operation
{A}	A	Detection mode of Augmented Reality.	Valid behavior
{T}	T	The target of AR was detected, and the augmented information was shown.	Valid behavior
{B}	B	Pressing the return button, the learner closed the augmented information and returned to the detection mode of Augmented Reality.	Valid behavior
{S}	S	The system was idle for more than one minute.	Valid behavior
{C}	C	The AR-reading assistant tool was switched off.	System operation
{E:j} {E:d} {E:u} {E:ac}	E	Problems occurred with the system and the program was terminated.	System operation

programming code is involved.

2.3 Experimental Design and Procedure

Our study adopted a quasi-experimental design, with a nonequivalent pretest-posttest control group design. The unit on astronomical observation in the science class of grade five elementary schools (Class A, Class C) and the unit on biology and environment of grade six (Class B) were used for testing. A pretest on learners' prior knowledge was given one week before the beginning of the experiment. The experiment was then conducted over 8 weeks, with 3 class sessions held every week. Each session lasted for 40 minutes, thus totaling 120 minutes of instruction per week. After the course unit ended, an assessment of learning achievement was conducted as a posttest. For the assessments, the instructor used an existing set of midterm examination questions as the basis and re-organized the order of question items as test questions for students. The difference between pretest and posttest were treated as the basis for calculating learning gains.

Before Class A and Class B began the study, the instructor uploaded all supplementary information for the course, including pictures, texts, and videos, onto the AR-assisted reading system using the authoring tools on the teacher's end. During class, each student was given a 7-inch Smart Phone, and by using the camera to scan text or picture paragraphs from the textbooks, the instructor's supplementary teaching materials were shown on the Smart Phone screen in the form of AR. The AR-reading assistant tool was not used for the entire class, but rather was used by matching the teaching progress and needs. Throughout the 8-week course, the total average time spent using the AR-reading assistant tool was 531.45 minutes (SD=34.456) for Class A and 351.29 minutes (SD=43.595) for Class B.

Class C used identical teaching materials to Class A, the only difference being that the AR-reading assistant tool was not used for supplementary teaching materials, and the instructor taught using lecture notes or PowerPoint presentations.

When the 8-week course was over, all participants filled out a questionnaire during the final lesson by connecting a Smart Phone to the website version of the VAK instrument. Learners were asked to fill in the questionnaire at the end of the course because we hoped that assessing the VAK style at that time would reflect the learning styles that students used and preferred specifically in their engagement with the AR tool, rather than any prior experience with various approaches to learning. For analysis, students from the two AR classes, Class A and Class B, were divided into three groups for consideration according to the VAK instrument. As the VAK instrument made an in-app connection through the AR-reading assistant tool, the VAK instrument was not administered in Class C.

2.4 Data collection and analysis

The mid-term exam and questions for the pretest and posttest were identical, with a possible score of 100, and served as an instrument to examine learning achievement in the unit taught. The questions themselves were the same as those that appeared on a normal mid-term exam. The instructor shuffled the order of the questions and question items prior to the experiment to create the pretest. Since significant differences already existed in the pretest with regard to the prior knowledge of learners of different learning style, improvements in learners' scores (posttest score minus pretest score) were used to perform one-way ANOVA statistical analyses.

The VAK instrument is a self-reported scale that was modified from the VAK learning styles self-assessment questionnaire [32] by Chislett and Chapman (2005). There were 30 questions in the original version, and after modifying the subjects and hints (Figure 2) to tailor it to the content of the experimental teaching course, the questionnaire was shortened to 10 questions. Each question had three options, representing choices for Visual, Auditory, and Kinesthetic respectively. Small changes to each question item were introduced randomly, to avoid cases wherein learners under testing might notice an obvious pattern of question items. The internal consistency (Cronbach's alpha) of the VAK instrument was 0.722. The classification of learning style types using the VAK instrument is not mutually exclusive, as many learners demonstrated two or more types of learning style. However, there are differences in the proportions of characteristics present from different styles. For example, in a learner with the characteristics V-40%, A-10%, and K-50%, the instrument classifies the learner as having a Kinesthetic preference (according to the learning style for which they had the highest proportion of characteristics).

※When I used AR-based tools but content is not shown, I would
A) Read the illustrations of the procedure, and think about what caused the problem
B) Ask for help from other classmates
C) Repeat the operation again, trial-and-error

Figure 2.The modified VAK instrument according to the contexts of the instructed course, translated from Chinese

Regarding the duration of operation of the AR-reading assistant tool, the system recorded a student's total amount of system use time (unit: minute) over the 8-week course duration, as well as the amount of time for system crash, error, and when students encountered operational problems. Since the total amount of time spent on the system was transmitted non-synchronously to the backend server through the Internet, this technological limitation produced an error rate of approximately ±5 minutes.

Furthermore, the AR-reading assistant tool documented all of a learner's operation sequences with the user interface and this information was then transmitted to the server in real time. Through the method of post-hoc coding of the log files (Table 1), participants' operation behavior in the AR-reading assistant tool was listed in a sequence for processing.

In the context of normal classroom usage, a learner would switch on the AR-reading assistant tool at the beginning of each lesson; he or she would log into the account and enter the course welcome page. The learner would then match the proceedings of the course and begin using functions of AR with a circular flow of coding {A}{T}{B}. Nonetheless, different learners had different habits of AR usage, as they would sometimes pause the AR operation and shift their attention elsewhere, such as to interact with classmates or focus on the textbook. In such cases, the system would begin to idle {S}. The detailed operation flow is as shown in Figure 3 with all possible transitions. We can observe the interaction between learners and the AR operation from the behavioral sequence {A}, {B}, {T}, {S}.

The operation behavior of all learners on the AR-reading assistant tool was processed by lag sequential analysis, and the first-order model was used for estimations. The data analysis tool used was designed according to principles from the research of Bakeman (1986) [36][37].

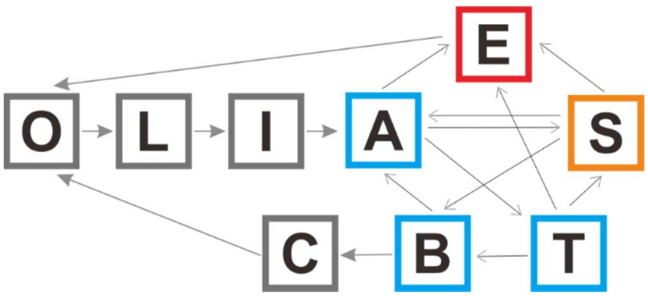

Figure 3. The operational flow of the AR-reading assistant tool

3. Results

After 8 weeks of instruction, all learners showed significant improvements with a pairwise t-test using their posttest scores (Class A, t=-8.276, p<.001; Class B, t=-7.001, p<.001; Class C, t=-8.756, p<.001). The overall mean pretest score was 75.12 (SD=11.878) and the overall mean posttest score was 89.26 (SD=8.862) (see Table 2), demonstrating that the instruction intervention was effective. Post Hoc Tests were performed using the Games-Howell method, and we observed significantly greater improvement in the scores of Class A and Class B than in those of Class C (Class A, p=.039; Class B, p=.001). There were also significant differences in the improvements of scores between Class A and Class B (p=.025). Furthermore, the experimental groups' (Class A, Class B) mean score on the pretest was 73.91 (SD=12.564), and their mean score on the posttest was 91.30 (SD=6.170). There was also a narrowing of standard deviation. For the control group (Class C), the mean score in the pretest was 77.39 (SD=10.356) and the mean score in the posttest was 85.43 (SD=11.657). In this case, narrowing of standard deviation was not observed.

Table 2. Descriptive statistics of the overall pre and posttests

	Score	Mean	N	Std. Deviation
Class A	pretest	78.82	22	6.631
	posttest	91.41	22	6.787
Class B	pretest	68.76	21	15.198
	posttest	91.19	21	5.618
Class C	pretest	77.39	23	10.356
	posttest	85.43	23	11.657

Since there were significant differences seen in the pretest scores between groups of different learning styles (F(2,40)=3.262, p=.049), the improvement in score (posttest score minus pretest score) was adopted as the criterion for statistical analyses. On average, Visual learners had an improved score of 16.12 (SD=11.24), Auditory learners had an improved score of 10.33 (SD=9.57), Kinesthetic learners had an improved score of 22.41 (SD=13.14). Furthermore, on average, learners in the control group improved by 8.04 (SD=4.41). The inter-group differences were significant after one-way ANOVA analyses (F(3,62)=7.703, p<.001).

Performing Post Hoc Tests with the Games-Howell method showed that Visual learners (p=.050) and Kinesthetic learners (p=.002) were significantly different from the control group, while improvement for Auditory learners (p=.898) was insignificant compared to the control. There was no significant difference in the degree of score improvement between Visual learners and Auditory learners (p=.527), which was also the case for Visual learners and Kinesthetic learners (p=.449), and Kinesthetic learners and Auditory learners (p=.062). Overall, Kinesthetic learners demonstrated the biggest improvement, followed by Visual learners, and there was least improvement in the control group (Figure 4).

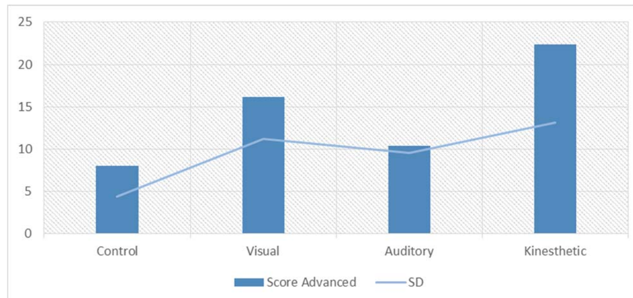

Figure 4. Comparison of improvements in scores between students of different learning styles and the control group

With regard to behavioral analyses, the amount of coding performed by Visual learners was 17,367, with a total of 17 fragments. On average, each fragment had 1,021 codes, where A→T, T→S, B→A, and S→B were highly significant behaviors, and A→E was a behavior with low significance (Figure 5). In the period following the presentation of augmented information, the majority of learners transferred their attention to other affairs, allowing the system to generate an idle message (T→S). Only on very few occasions did the learner directly press the return button to re-detect the target of augmented reality (T→B). In the process of using AR, this group of learners more often encountered barriers such as automatic logging-out of the system (A→E). It is worth noting that Visual learners rarely had idle behavior during the detection mode of AR (A→S).

The amount of coding performed by Auditory learners was 8,015, with a total of 9 fragments, each of which had on average 991 codes. A→T, T→S, B→A, and S→B were highly significant behaviors, while A→S, S→A, and T→B were behaviors with low significance (Figure 6.). As compared to Visual learners, the biggest difference found was that Auditory learners had significant idle behavior (A→S, T→S) during both the AR detection stage (A) and the presentation of augmented information (T) stage. This illustrated that Auditory learners had relatively lower adherence to AR, and their attention could easily be diverted to other instruction media or events.

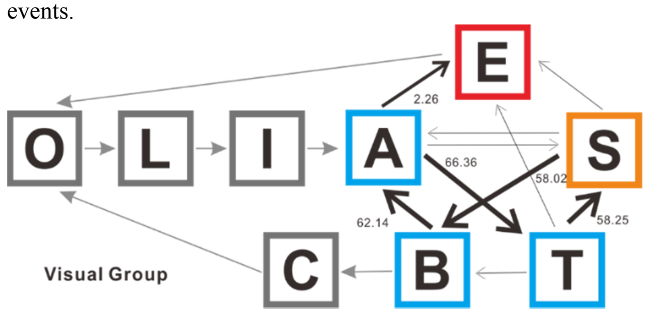

Figure 5. Behavioral patterns of the Visual Group. (Z-Score)

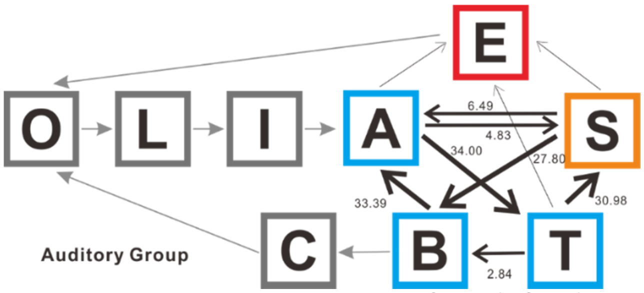

Figure 6. Behavioral patterns of the Auditory Group. (Z-Score)

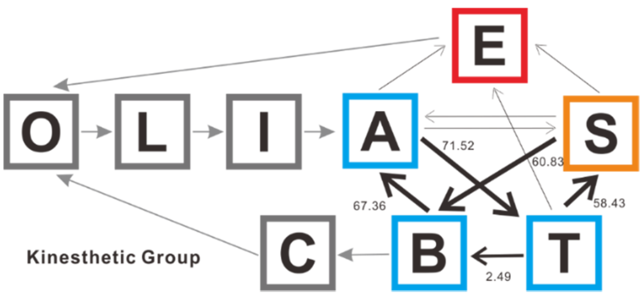

Figure 7. Behavioral patterns of the Kinesthetic Group. (Z-Score)

The amount of coding performed by Kinesthetic learners was 19,286, with a total of 17 fragments. On average, each fragment had 1,134 codings, among which A→T, T→S, B→A, and S→B were highly significant behaviors, while T→B was a behavior with low significance (Figure 7.). During the main operation cycle (A→T→B→A), Kinesthetic learners did not enter the idle mode easily (S). The only moment when idleness emerged significantly followed the appearance of augmented information, when learners might have been affected by factors related to the course proceedings and were thus forced to stop (T→S). Nevertheless, the probability of idleness (Sp) emergence among Kinesthetic learners (Sp=0.2137) was lower than among Visual learners (Sp=0.2324) and Auditory learners (Sp=0.2794) (Table 3.). Moreover, the amount of coding used for each fragment was higher than for their counterparts, implying that when taking the same course, Kinesthetic learners used the AR-reading assistant tool more frequently, and there was a lower probability of them diverting their attention to other media.

Table 3. Frequency and probability of behavioral patterns

		A	T	B	S
Visual	Frequency	4670	3732	3695	3691
	Probability	0.2941	0.2350	0.2327	0.2324
Auditory	Frequency	2383	1364	1331	2002
	Probability	0.3326	0.1904	0.1858	0.2794
Kinesthetic	Frequency	5185	4317	4233	3772
	Probability	0.2937	0.2445	0.2398	0.2137

For considering the probabilities of idleness emergence for all experimental groups and the final improved scores, the correlation coefficient was -0.211(p=.173), showing that the more often idleness occurred, the less the learner's improvement in score (Figure 8.). In addition, other than Kinesthetic learners from Class B, the correlation between the cumulative amount of time using the AR-reading assistant tool and learners' improved scores was medium to high. This was the case for all experimental groups (Table 4.), although the significance was not high. Kinesthetic learners from Class B showed a weak negative correlation.

Table 4. The correlation between cumulative used time and scores advanced

	Visual	Auditory	Kinesthetic
Class A	r=.524, p=.120>.05	r=.642, p=.556>.05	r=.550, p=.125>.05
Class B	r=.430, p=.355>.05	r=.766, p=.075>.05	r=-.378, p=.356>.05

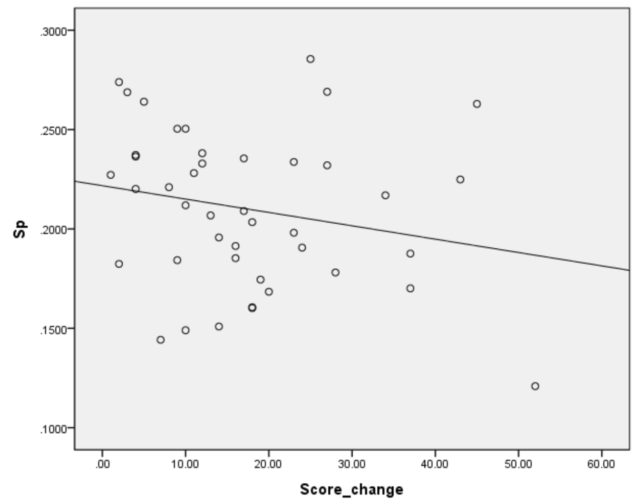

Figure 8. The relationship between idleness occurred and the learner's improvement in score

Finally, given that an exclusive classification of one learning style per student is not an accurate representation of the diversity of approaches that might work for a learner, we additionally ran an analysis to investigate whether learning gains were similarly related to the *degree* to which a learner expressed a preference for learning with a particular approach. Therefore, all experimental groups' data, using the raw VAK scores rather than the post-hoc classification, were input into a multiple regression analysis (MRA) employing a Stepwise method. The results show that the score change between pre-test and post-test is indeed influenced by the level of Kinesthetic preference, as well as their class. The MRA function is shown below:

$$Y=-6.496+2.574*K+9.375*Class$$

4. Discussion

Focusing on overall learning gains from using an AR-reading assistant tool, all learners showed significant improvement after the 8-week course. The experimental group in which the AR-reading assistant tool was introduced had significantly larger improvements than the control group. This implies that the hypothesis that AR can effectively enhance students' learning efficacy was proved valid in this study.

Across all learners who had the AR intervention, we additionally found that intra-group standard deviation decreased significantly on post-test scores. This result matched the conclusion from the research of Zhang, et al (2015), that effective AR-assisted instruction can narrow the standard deviation of learning achievements, thus increasing the homogeneity of learning [15].

Despite this result, there were observed differences for particular groups of students. First, Class B from the experimental group had significantly larger improvements than Class A. Although the fundamental instruction strategies and flow of the two classes were controlled, due to research limitations, the two classes were of different grades and used different units of instruction. They also differed in terms of the accumulated time spent using the AR-reading assistant tool. The performance of learners from Class B was observed to be superior to those from Class A, possibly due to the fact that AR adapted differently to the different grades and instruction units, thus resulting in differences in efficacy. It is less likely that this difference stemmed from the accumulated duration of use of the AR-reading assistant tool. Due to more limited content of the instruction unit, learners from Class B spent a shorter time than their counterparts from Class A using AR. If we hypothesize that the shorter the cumulative usage time, the greater the improvements in results, this would contradict the testing results in the second half of this article on each learning style type and the grouping of classes; according to the relevant testing results from the Pearson statistic, for each group under the same conditions, the longer the usage time of AR, the greater the degree of improvement in results. Also, based on the MRA result, score improvement was only significantly related to class (beyond the VAK scores). Thus we suspect that AR has different suitability for different grades and instructional units.

In addition, from the learning gain results, we observed that AR had different efficacy for learners who expressed different learning style preferences. Based on the t-test results and MRA, AR had more significant efficacy for the Kinesthetic learners than on other groups. The MRA results show that the learning gains depended on the degree of preference for Kinesthetic approaches.

Through lag sequential analysis, we found that when Kinesthetic learners were using the AR-reading assistant tool, they had a lower probability of device idleness, so were less likely to divert their attention to other instructional media or to their peers. Moreover, through relevant calculations, it was revealed that the higher the probability of idleness appearing in the overall behavioral sequence, the lower the final learning efficacy. To a certain extent, this implied that learners were becoming less affected by the AR-assistant tool and its augmented content. Alternatively, with Auditory learners we observed from their behavioral sequence that these learners often left the tool in an idle status, indicating a higher chance that they were concentrating on other instructional media at that time. This eventually resulted in no significant difference in their learning efficacy when compared to the control group. Based on this result, we conclude that AR is more suitable for learning among Kinesthetic learners.

There is also a certain connection between the operation of AR and the way in which the classes were taught. The class format of the control group was geared more towards instructor lecturing, and listening and reading by learners, whereas AR increased the opportunity for hands-on activities. Thus, comparatively speaking, AR could further support and strengthen Kinesthetic learners' passion and concentration. From a different point of view, when a tool such as AR is used, if a Kinesthetic instruction strategy can be adopted, it might improve its adaptability. It has also been noted in previous literature that the operational characteristics of AR could enhance users' visual concentration [2][25][26][37][38][40]. Thus, our study similarly expected that Visual learners would have better learning efficacy. However, after statistical testing, despite the learning gains found in the group of Visual learners as compared to the control group, the significance level was at the borderline range ($p=.050\leq.05$). Thus, we remain careful with this inference.

The cumulative time spent on AR mostly adhered to our prediction. If AR can aid learning efficacy, then, theoretically speaking, the longer the intervention time, the better the learning efficacy. According to the correlation coefficient testing, with Class B's Kinesthetic learners as the exception, the longer the AR usage time of each group under identical conditions, the greater the improvement in their results. Through post-experiment feedback from the instructor, we learned that some learners were distracted during lessons. They might have been concentrating on operating the Smart Phone rather than on actual learning content. It happened to be the case that Class B only had 9 Kinesthetic learners. Thus, there is a possibility that a small number of participants significantly affected the overall scenario. Nonetheless, from the overall macro perspective, we cannot exclude the possibility that the longer the AR usage time, the greater the degree of improvement in results.

5. CONCLUSIONS

According to the research results, our study found that:

(1) Based on this study and literature reviews, using AR to assist science instruction in elementary schools could effectively enhance learning gains for many students.

(2) Use of AR can have a particularly supportive role for learners who have preferences for Kinesthetic approaches to learning, and possibly for learners with preferences for Visual approaches as well.

(3) AR had less effect on attracting the attention of Auditory learners in elementary school science instruction.

The existing research literature has argued that matching appropriate tools to specific learning styles could enhance learning more effectively [41]. Nonetheless, as compared to arguments about unchanging learning styles [42][43], some researchers have argued that learning styles are also influenced by factors like study location and environment [44]. Therefore, whether the use of AR tools can also change learners' learning style preferences is an issue worthy of further exploration in the future.

Lastly, we suggest that when applying AR as a means to enhance learning in science instruction in elementary schools, one can design the tool by focusing on different learning styles, and enhance the potential learning efficacy by attracting learners' attention to the learning media through AR characteristics. Noting the interactive effect between different learning styles and AR, our study also recommends that if AR can be integrated into adaptive instruction strategies in the future, its potential can be further realized for supporting learning efficacy.

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