Exploring the Mechanisms for Implementing AR-based Learning Activities through the Lens of Motivational Design

Yun Wen*, Sujin He
1 National Institute of Education, Nanyang Technological University, Singapore
* yun.wen@nie.edu.sg

Abstract: *The application of Augmented Reality (AR) in science and its potential have been widely recognized. Research generally suggests that AR can enhance students' motivation in learning, though findings on whether AR improves academic performance remain inconsistent. This mixed methods quasi-experimental study, which examined the use of a developed AR-assisted learning app in science classrooms, confirmed the critical role that teachers play in implementing AR-enhanced inquiry activities. Additionally, the study analyzed teaching mechanisms for the effective use of AR-enabled learning, offering specific suggestions for AR instructional designers and teachers to effectively design and implement AR activities into teaching practices.*
Keywords: Augmented Reality, ARCS, Motivation, Primary School, Science

1. Introduction

The past decade has seen a development in the number of Augmented Reality (AR) applications being used in education. Although studies have shown the benefits in using AR for students (Chang et al., 2023), there are certain implications that educators should be mindful of. The effective use of AR also requires the adoption of suitable pedagogical approaches and teaching strategies (Garzón et al., 2020; Wen et al., 2023). Pedagogical models that provide practical strategies for designing teaching processes and resources, such as Keller's ARCS model (1987), have been used to promote learners' engagement in AR-supported learning environments (e.g., Hao, 2023; Li et al, 2023). While teachers envision the advantages in adopting AR-enhanced learning, they may lack the necessary competencies for AR implementation (Nikou et al, 2023). Furthermore, managing students are challenges that teachers face, and if not given adequate support, may result in the teacher feeling overwhelmed and not able to fully capitalise on AR's affordances, ultimately missing out on potential teaching opportunities. However, few studies focus on understanding the prerequisites for teachers or specific mechanisms to implement AR activities effectively in classrooms. Therefore, the purpose of this study is to investigate which specific real-time mechanisms employed by teachers in implementing AR-supported learning activities may influence students' learning motivation and their learning performance.

2. Literature Review

This study is grounded in Keller's ARCS model (Attention, Relevance, Confidence, Satisfaction) (Keller, 1987). It has been effectively applied to technology-enhanced learning environments, serving the needs of educational research and practice (Ma & Lee, 2021). Motivation has been identified as a crucial factor in learning that affects students' academic achievement and emotion (Shapiro et al., 2017), so motivation is an important component from which instructional design can be understood. There are also other motivational design models; however, earlier models often concentrate on specific motivational characteristics, such as achievement motivation. In contrast, the ARCS model takes a more holistic approach to designing motivating learning environments.

Keller's model (1987), comprising four components of attention, relevance, confidence, and satisfaction, demonstrates a motivational design strategy by first capturing and sustaining learners' attention, while triggering their curiosity. Next, relevance requires learning activities to be aligned with the individual goals and needs of learners for it to be perceived as meaningful. The model also emphasized that learners' confidence can be fostered by their sense of control and their expectations of success, as it impacts the effort, they are willing to invest in the activities. Lastly, learners’ completion of learning goals will impact their level of satisfaction and cultivate a sense of reward and pride (Li & Keller, 2018). Keller outlined these four major components that need to be present for learners to feel motivated and sustain that motivation.

Studies have shown that the use of AR technology in educational settings can help enhance motivation (e.g. Silva et al., 2023). For instance, as reported in the systematic review by Garzón et al. (2019), motivation was the second most frequently reported benefit of AR use in classrooms. The overlay of 3D virtual elements in a real-world setting provides an immersive quality that captures learners' attention, creating a learning environment that can enhance motivation (Xu et al., 2022). Moreover, the contextualized scenarios provided by AR technology can bridge the gap between the theoretical content and real-world application (Lin et al., 2023). The AR elements can provide authentic learning scenarios which help students see the relevance of their learning. This can engage students further, motivating them through a sense of purpose and meaning. Although a growing number of studies have paid attention to the design of AR learning environments guided by ARCS model (e.g., Hao & Lee, 2021; Laurens-Arredondo, 2022), there is scarcity of research on teachers’ implementation strategies that reflect the ARCS model in AR environments to ensure the effectiveness of design.

1. What are the effects of AR-based learning approach guided by ARCS design on students’ academic performance and learning motivation?

2. What mechanisms used by teachers during the implementation of AR-based learning may affect students’ learning motivation?

3. Methods

3.1. Participants

This study was carried out in three Singapore primary schools on the topic of digestion. It involved grade 4 students (10 – 12 years) from 10 classes, along with their science teachers. The duration for the study was for a period of over three weeks. The learning objectives for all the classes were similar, based on the curriculum. However, 6 classes from the 3 schools used the AR app “The Doctor’s Digest” to learn about digestion, while 4 control classes from the same schools did not.

For the experimental classes, the teachers used the AR Doctor’s digest app together with AR designed worksheets. Additionally, they also covered worksheets from the school’s official Textbook. Each lesson began with a brief introduction to the Digestive system and a demonstration of how to use the AR app. Students then used the ipads to complete the AR activities and worked in groups of three or four. For the control classes, students were taught using traditional teaching methods without the use of AR. The control class lessons included teacher-led lectures and teacher-led class discussions. Teachers presented the concepts using visual aids such as PowerPoint slides and showed videos to complement their lectures. Both the experimental and control classes completed the same worksheets from the school’s official Textbook.

3.2. AR-based learning guided by ARCS design on the topic of digestive system

The app’s storyline is designed for students to assume the identity of a doctor. The task is to diagnose and treat patients who are facing various digestive problems. This interactive approach aims to introduce students about the digestive system and related health issues in authentic real-life scenarios. The app comprises four activities – “Training simulation”, “What happens?”, “Case Files” and “Create an alien”. Figure 1a shows the interface of the “what happens” activity, and Figure 1b shows the teacher helping the group take a photo with the AR alien they created in the last activity. All the AR learning activities are aligned with students’ science syllabus. A teacher’s dashboard, designed alongside with the AR app, enables teachers to monitor students’ group work progress and performance. The dashboard can also support students in monitoring and reflecting on their group’s progress.

"Training simulation" gives an overview of the digestive system, where students have to position the different digestive organs (mouth, gullet, stomach, small intestine, large intestine, anus) correctly, in order to activate a simulation of how digestion occurs. For "What happens?", students are given situations such as "What do you think will happen to the digestive system if the small intestine is too short." Students need to apply what they have learnt and give reasons for their explanations. In "Case Files", students need to diagnose digestive issues that the patients are experiencing, based on the symptoms presented in the case files. They will observe a simulation of the digestive problem, apply their knowledge, and select the appropriate remedy from the provided options for the specific digestive issue. The final activity, "Create an Alien", is meant to consolidate and provide a synthesis of the digestion concepts taught. In this activity, students are given hypothetical scenarios in imaginary planets (e.g., climate with little rainfall) where the aliens have access to only certain types of food (e.g., only vegetables). Based on these conditions, they are tasked with designing a digestive system that is specifically adapted to the alien's environment and available food sources (e.g., sharp teeth, long gullet).

(a) students reviewing the simulation (b) students taking a photo with the alien they created

Fig.1 Students working on the "what happens" and "create an alien" activity in groups

3.3. Data Collection

To investigate students' learning performance, pre-and post-tests were administered before and after the intervention. There were three multiple-choice questions (6 marks) and two open-ended questions (6 marks) for the pre-test, with a total score of 12 marks. For the post-test, the questions were different but of a similar difficulty level. To explore students' learning motivation, a motivation survey questionnaire was adapted and rewritten to fit the learning content of this study, based on the measurement scale used by Hao and Lee (2021). The questionnaire consisted of 18 items in total. All the students from the 10 classes were invited to complete both the pre- and post-surveys, as well as the pre- and post-tests. After cleaning the raw data, 287 valid responses were keyed into the SPSS.

The reliability of the questionnaire was tested and showed that the questionnaire and its four subscales of attention (Cronbach's α = .91), relevance (Cronbach's α = .83), confidence (Cronbach's α =.84), and satisfaction (Cronbach's α =.91) were reliable in terms of internal consistency. Then, the data were subjected to a confirmatory factor analysis (CFA) to test the construct validity of responses to the questionnaire. The values of composite reliability (CR) for the four subscales of the questionnaire were acceptable with values greater than 0.7 (Fornell & Larcker, 1981), and the convergent validity (AVE) was acceptable with values greater than 0.5 (Peterson, 2000). A satisfactory model fit was obtained ($\chi 2$ (126) = 256.6, $p < .001$, CFI = .968, RMSEA = .059, SRMR =.032) (Hair et al., 2010).

We also video recorded all the AR classes to analyse how teachers conducted the AR lessons. During the classroom interventions, the research team set up 2 video cameras to collect classroom observation data. Focus-group students' interviews were conducted after all the AR lessons.

3.4. Data Analysis

The data was analysed in two phases. In the first phase statistical analysis was done to investigate the effect of the AR-based learning approach. In the next phase, the case classes were chosen based on their learning performance, and content analysis was conducted to investigate teachers' instructional events. A one-way factorial ANCOVA analysis was conducted to examine the academic differences between the AR and non-AR groups by taking the students' pre-test results as a covariate variable. To understand students' perceptions towards motivational design upon using different teaching approaches, MANCOVA was conducted to examine motivations from four aspects. The pre-survey results served as the covariant to eliminate the differences in students' motivation.

Content analysis was conducted to analyse the instructional events by systematically categorizing code and identification of themes (Hsieh & Shannon, 2005). Content analysis was conducted in the order of (1) identifying all class-level instructional events, (2) categorising the mechanisms reflected instructional motivation. The coding was done with the Behavioural Observation Research Interactive Software (Boris).

Based on students' learning performance, two case classes were selected to investigate how the teachers implemented the AR lessons. The teacher's class level instructions were first segmented by themes for further analysis. Teachers' discourse within small groups were excluded. The class-level instructions were segmented in terms of different themes, for instance, the instructional events for introducing learning objective, providing feedback etc. The unit of analysis of this study refers to every meaningful teacher-to-class instructional event. In the second phase of video-based content analysis, the case classes' instructional events were explored in detail to detect enactment mechanisms for promoting learning motivation (Tabel 1). The second author helped code the video data in terms of the coding scheme. To check coding reliability, the first author coded the data separately, and the interrater reliability was over 0.92 (Cohen's kappa). Additionally, students' post-interview data were cited to triangulate the findings of content analysis.

Table 1. Coding scheme for mechanisms to stimulate motivation

ARCS Dimensions	Observed Strategies
Attention	A1. Initiating the topic by asking questions
	A2. Introducing AR functions
	A3. Introducing AR activities
Relevance	R1. Introducing learning objectives
	R2. Explaining the linkage between AR tasks and worksheets
Confidence	C1. Providing details on expectations of activities and role assignment
Satisfaction	S1. Providing feedback about group work progress
	S2. Providing feedback about students' understanding
	S3. Providing feedback about the group of students

4.Findings

4.1. The effects of the designed AR-based learning environment on students' academic performance

As shown in Table 2, the ANCOVA result showed a nonsignificant result $F(2, 280) = 2.53$, $p = .111$, $\eta 2 = .009$, indicating that no differences on academic performance were found between the AR and non-AR approaches. Nevertheless, when we paid attention to the pre-test and post-test performance of each AR class, we found the class's performance were diverse (see Table 3). In this study, we selected AR2 and AR4 classes as case classes as their post-test scores were the highest and lowest respectively after the intervention.

Table 2. the one-way ANCOVA result of the academic performance of the two conditions

Group	N	Adjusted Mean	Adjusted SD	*F*	*P*	*η2*
AR Classes	154	7.35	.24	2.53	.112	.009
Non-AR Classes	133	6.79	.26			

Table 3. Students' academic performance in each AR class

Class	N	Pre-test		Post-test		*t*	*p*
		Mean	SD	Mean	SD		
School A_AR1	31	4.60	2.01	8.73	1.78	8.33	<.001
School A_AR2	34	6.79	3.30	9.79	1.67	5.40	<.001
School B_AR3	37	3.27	2.06	6.10	2.91	5.85	<.001
School B_AR4	20	2.30	1.45	3.40	2.67	2.05	.055
School C_AR5	21	4.85	2.48	8.29	2.10	5.93	<.001
School C_AR6	26	4.62	1.92	6.27	2.82	2.66	.014

4.2. The effects of the designed AR-based learning environment on students' learning motivation

The group means on attention, relevance, confidence, and satisfaction are shown in Table 4. The Levene's tests of equality of error variances were not significant, indicating that the assumption of equal error variance of the dependent variables across groups was met. The multivariate result for the effect of the AR approach showed statistical significance, $F(4, 278) = 2.94$, $p = .021$, $\eta 2 = .041$, indicating that students from the AR classes showed higher learning motivation compared to those from the non-AR classes. Univariate tests showed an effect of the AR approach on students' attention perception, $F(1, 281) = 5.38$, $p = .021$, $\eta 2 = .019$ (see Table 5). Students in the AR classes reported to have higher attention perception than those in the non-AR classes ($p < 0.05$). However, the AR approach did not impact on students' perceptions of relevance, confidence, and satisfaction significantly.

Table 4. Descriptive findings of students' learning motivation

Motivation	AR (*n* = 154)		Non-AR (*n* =133)	
Subscales	Mean	SD	Mean	SD
Attention	3.92	.94	3.67	.92
Relevance	3.96	.85	3.93	.77
Confidence	3.85	.94	3.73	.94
Satisfaction	4.13	.87	4.02	.82

Table 5. MANCOVA summary of students' motivation

Motivation Subscales	*F*(1, 281)	*P* Value	Partial *η2*
Attention	5.38	.021	.019
Relevance	.07	.79	.000
Confidence	.56	.46	.002
Satisfaction	.73	.38	.003

In the post-interview, students from the AR groups all shared that they were particularly drawn to the realistic simulations and interactive elements in the AR app. These features likely captured their attention more effectively than traditional teaching methods due to their immersive and hands-on qualities, allowing students to explore and manipulate the content independently rather than merely observing a teacher's demonstration.

Table 6. Descriptive findings of students' learning motivation about the two cases

Motivation	School A_AR2		School B_AR4	
Subscales	Pre	Post	Pre	Post
Attention	4.04 (.68)	4.35 (.62)	3.75 (.67)	3.48 (1.10)
Relevance	4.46 (.45)	4.44 (.53)	3.78 (.62)	3.53(.87)
Confidence	3.93 (.80)	4.23 (.73)	3.73 (.67)	3.45 (1.03)
Satisfaction	4.51 (.43)	4.65 (.47)	4.03(.65)	3.68(.83)

As shown in Table 6, we further examined the learning motivation data from the two case classes and observed improvements across all four motivation subscales in the AR2 class. However, no significant improvements were detected in the AR4 class, in which students' pre- and post-test scores had no significant improvement.

4.3. Observed implementation mechanisms in the case classes

Based on the results of the content analysis, we compared the strategies employed by teachers while enacting AR lessons (see Table 7). A notable difference was observed in the approach taken by the teacher of the AR2 class, who engaged students in the digestive system topic at the beginning of all activities by asking questions (14min 42sec). Aligning with inquiry-based learning, this strategy effectively sparked students' interest and prompted them to generate their own set of questions related to the topic. In terms of attracting students' attention, another key difference was that the AR2 teacher spent time thoroughly explaining the features of the AR app including the user interface and the function of buttons (8min 26sec), rather than only explaining the design of AR activities (6min). Regarding learning objectives, the AR2 teacher did not repeatedly highlight them (1mins28sec), as the AR4 teacher did (6min 26sec), but both teachers reminded students of the connection between AR app activities and the worksheet.

During the activities, the AR2 teacher occasionally encouraged students to collaborate with one another (18sec). More importantly, the teacher used the dashboard to collect students' responses to the open-ended questions and provide content-related feedback accordingly (33min 44sec). For example, the AR2 teacher organized and projected all groups' responses and commented on the completeness of their answers, thereby promoting a better understanding and application of targeted concepts. However, because such summarization took time, she did not not provide this feedback at the end of each lesson, but at the beginning of the following AR lesson, to address issues identified based on students' inputs.

In contrast, this strategy was less observed in the AR4 class (6min 50sec). The AR4 teacher tended to provide content-related summaries and feedback at the end of each activity. The AR4 teacher frequently used the dashboard to monitor group progress during the activity (13min 15sec). He occasionally praised faster groups and reminded slower groups to catch up, offering assistance when necessary. The AR2 teacher, however, did not intentionally praise specific groups for their progress. Furthermore, during AR activities, the AR2 teacher chose not to project her teacher dashboard onto the screen for students, contrary to our suggestion. She explained that her students were typically highly engaged in learning activities, and projecting group progress might unnecessarily heighten their sense of competition.

Table 7. a comparison of used strategies for promoting students' learning motivation in the two case classes

ARCS dimensions	Observed Strategies of Enactment	School A_AR2		School B_AR4	
		f	Length (mm:ss)	*f*	Length (mm:ss)
Attention	A1. Initiating the topic by asking questions	1	14:42	0	0
	A2. Introducing AR functions	4	8:26	5	5:16
	A3. Introducing AR activities	4	6:00	8	13:51
Relevance	R1. Introducing learning objectives	2	1:28	3	6:26
	R2. Explaining the link between AR tasks and worksheets	6	4:19	2	3:32
Confidence	C1. Providing details on expectations of activities and role assignment	2	0:18	0	0
Satisfaction	S1. Providing feedback about group work progress	3	2:39	19	13:15
	S2. Providing feedback about students' understanding	7	33:34	2	6:50
	S3. Providing feedback about the group of students	0	0	2	1:36

The interview data from the two classes also highlighted obvious differences in their experiences during the AR lessons. These differences were mainly reflected in two aspects: (1) familiarity with the AR app and (2) students' reflection on their group collaboration. However, students from both classes were highly consistent in their responses regarding whether the AR activities were engaging compared to teacher-led lessons. They all agreed that the visualization and hands-on approach were more interesting.

AR4 students mentioned that they sometimes struggled with operating the app and expressed dissatisfaction with their group's performance during the activities. Students from AR4 Group 7 shared that they faced challenges during the first AR lesson. Although the teacher showed them how to use the AR app, they still did not fully understand it until the second AR lesson, when the teacher used the PowerPoint slides to guide them and explain the functions. AR4 Group 2 students noted that while the teacher's explanation helped them understand how to carry out the AR activities, their bigger challenge was not knowing how to collaborate. This hindered the smooth progress of their activities, making the experience less enjoyable. AR4_G2S3 said "The first activity was quite fun until everyone started to get angry and didn't get along with each other." AR4_G2S1 added "in our training simulation (the first activity), everyone started going out of control. We have no teamwork." AR4_G2S3 further explained "Everyone got different answers. We don't know who has the correct answer, the problem is still a problem and then we don't know what to do, how are we supposed to know." Regarding the usefulness of the dashboard, AR4 Group 2 mentioned that, initially, we paid attention to it and noticed their team was working somewhat slowly. After a few AR lessons, they noticed other groups had improved, but their own team had not. This left them feeling frustrated.

On the contrary, when asked their feedback on group work. AR2_G3S1 said "quite good, we build team bonding. It was quite difficult to handle the iPad and the pieces of paper together so in a group it would be easier". When asked how they resolved differences in opinions, they added that "… just try out both ways and see which one is more correct." AR2 Group 4 students also agreed that working in a group helped them learn better.

5. Discussion

There was no significant difference in academic performance between AR and non-AR classes across the 10 classes analyzed. However, from the perspective of learning motivation, AR classes showed significant improvement in the attention dimension. n some AR classes, both students' learning motivation and academic performance showed significant improvement, attributed to the effective use of AR. Our data suggest that these outcomes are closely related to how teachers implemented AR activities. Based on the results from the comparative cases, we identified three implementation mechanisms: (1) Thoroughly introducing AR functions at the start of lessons; (2) Tailoring feedback on regulation based on students' readiness to pedagogical approaches; (3) Using AR activities to promote a new cycle of inquiry.

First, when introducing AR apps into the class, especially for the first time, it is essential to allocate sufficient time to explain its features comprehensively. While AR with 3D simulations can naturally capture students' attention and boost their motivation, the novelty effect may diminish as students encounter challenges in continuing the activities. As AR environments are relatively unfamiliar to most students, teachers need to focus initially on explaining AR's functions rather than diving directly into the activities.

Second, feedback during AR activities should consider students' readiness for the pedagogical approach. In our study, classes with less observable improvement included students lacking collaborative learning skills. Socially shared regulation of learning is critical for students' collaborative learning engagement (Järvelä et al., 2020), and affects their cognitive, motivational, and emotional states (Edwards et al., 2024). Projecting dashboards to students may help them to monitor and reflect on their group work progress. Nevertheless, teachers should clearly articulate their expectations and take into account the specific characteristics of the pedagogical approach if it is unfamiliar to their students. Additionally, they need to spend additional time coordinating group progress. Teachers' feedback should be provided beyond reminding students' keep monitoring their group progress, but how to negotiate with one another and make consensus.

Last, in AR classes, teachers need to focus on identifying students' knowledge gaps through their performance in the activities and promoting deeper understanding via further inquiry, so as to improve student' satisfaction with learning effectively. This finding aligns with the motivational AR-based learning approach proposed in Li et al.'s study (2023), which highlights the importance of discussion between teachers and students in fostering students a sense of accomplishment and satisfaction. Overemphasizing feedback on students' work progress while neglecting content-related feedback may leave students feel struggled or unsupported. Studies (Carless & Winstone, 2023) have emphasized the importance of avoiding delays in providing post-task feedback. However, this does not mean that such feedback must always be provided within the same lesson. Feedback can also be provided in subsequent lessons, as ICT tools often record students' inputs, enabling teachers to prepare more tailored feedback based on students' performance. Therefore, when integrating AR apps into classroom teaching, it is crucial to allocate sufficient time for completing activities and deepening discussion to ensure their effectiveness.

6. Conclusion

This study confirmed the positive impact of the AR-based learning approach, guided by the ARCS design, on students' academic performance and learning motivation in primary science classes. It highlighted the pivotal role of teachers in the implementation process and identified three key mechanisms to enhance student motivation. However, the study also has limitations. The most significant limitation lies in the need to account for differences in class contexts. The mechanisms we identified are based on two comparative cases. However, the students of these classes differed notably in their academic performance levels and familiarity with collaborative learning before the intervention. The intent of this comparison is not to evaluate teachers' enactment but uncover potentially effective approaches and shed light on challenges that can be addressed. Future research could take class contexts into account to further validate and refine these mechanisms.

References

Carless, D., & Winstone, N. (2023). Teacher feedback literacy and its interplay with student feedback literacy. *Teaching in Higher Education*, *28*(1), 150-163.

Chang, C. Y., Kuo, H. C., & Du, Z. (2023). The role of digital literacy in augmented, virtual, and mixed reality in popular science education: a review study and an educational framework development. *Virtual Reality*, *27*(3), 2461-2479.

Edwards, J., Nguyen, A., Lämsä, J., Sobocinski, M., Whitehead, R., Dang, B., ... & Järvelä, S. (2024). Human-AI collaboration: Designing artificial agents to facilitate socially shared regulation among learners. *British Journal of Educational Technology*.

Garzón, J., Baldiris, S., Gutiérrez, J., & Pavón, J. (2020). How do pedagogical approaches affect the impact of augmented reality on education? A meta-analysis and research synthesis. *Educational Research Review*, *31*, 100334.

Garzón, J., Pavón, J., & Baldiris, S. (2019). Systematic review and meta-analysis of augmented reality in educational settings. *Virtual Reality*, *23*(4), 447-459.

Hair, J. F. J., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). *Multivariate data analysis: A Global perspective* (7th ed.). Upper Saddle River, NJ: Pearson Education.

Hao, K. C. (2023). Creating a DGBL integrating ARCS motivation theory with animation, narrative story, fun, and usability to enhance learning motivation and effectiveness. *Interactive Learning Environments*, 31(9), 5698–5714.

Hao, K. C., & Lee, L. C. (2021). The development and evaluation of an educational game integrating augmented reality, ARCS model, and types of games for English experiment learning: an analysis of learning. *Interactive Learning Environments*, *29*(7), 1101–1114.

Hsieh, H. F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative health research*, *15*(9), 1277-1288.

Järvenoja, H., Järvelä, S., & Malmberg, J. (2020). Supporting groups' emotion and motivation regulation during collaborative learning. *Learning and Instruction*, *70*, 101090.

Keller, J. M. (1987). Development and use of the ARCS model of instructional design. *Journal of Instructional Development*, 10(3), 2–10.

Laurens-Arredondo, L. (2022). Mobile augmented reality adapted to the ARCS model of motivation: a case study during the COVID-19 pandemic. *Education and Information Technologies*, *27*(6), 7927-7946.

Li, K., & Keller, J. M. (2018). Use of the ARCS model in education: A literature review. *Computers & Education*, *122*, 54-62.

Li, M., Chen, Y. T., Huang, C. Q., Hwang, G. J., & Cukurova, M. (2023). From motivational experience to creative writing: A motivational AR-based learning approach to promoting Chinese writing performance and positive writing behaviours. *Computers & Education*, *202*, 104844.

Lin, X. F., Hwang, G. J., Wang, J., Zhou, Y., Li, W., Liu, J., & Liang, Z. M. (2023). Effects of a contextualised reflective mechanism-based augmented reality learning model on students' scientific inquiry learning performances, behavioural patterns, and higher order thinking. *Interactive Learning Environments*, *31*(10), 6931-6951.

Ma, L., & Lee, C. S. (2021). Evaluating the effectiveness of blended learning using the ARCS model. *Journal of Computer Assisted Learning*, *37*(5), 1397–1408. https://doi.org/10.1111/jcal.12579

Nikou, S. A., Perifanou, M., & Economides, A. A. (2023). Development and validation of the teachers' augmented reality competences (TARC) scale. *Journal of Computers in Education*.

Shapiro, H. B., Lee, C. H., Roth, N. E. W., Li, K., Çetinkaya-Rundel, M., & Canelas, D. A. (2017). Understanding the massive open online course (MOOC) student experience: An examination of attitudes, motivations, and barriers. *Computers & Education*, *110*, 35-50.

Silva, M., Bermúdez, K., & Caro, K. (2023). Effect of an augmented reality app on academic achievement, motivation, and technology acceptance of university students of a chemistry course. *Computers & Education: X Reality*, *2*, 100022.

Wen, Y. Wu. L., He. S. J., Ng., H-E., Teo., B. C., Looi, C-K. & Cai, Y. (2023) Integrating Augmented Reality into Inquiry-based Learning Approach in Primary Science Classrooms, *Educational Technology Research & Development*. *71*, 1631–1651.

Xu, X., Kang, J., & Yan, L. (2022). Understanding embodied immersion in technology-enabled embodied learning environments. *Journal of Computer Assisted Learning*, *38*(1), 103-119.

Acknowledgments

This study is funded by MOE SSHRF 8/22 WY. The views expressed in this paper are the author's and do not necessarily represent the views of the host institution.