Entertainment Computing 46 (2023) 100563

Contents lists available at ScienceDirect

Entertainment Computing

journal homepage: www.elsevier.com/locate/entcom

The effect of fantasy on learning and recall of declarative knowledge in AR game-based learning

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A B S T R A C T

With increasing research attention on the application of Augmented Reality (AR) and Game elements in education, fantasy elements as imaginary, fictional game features have been shown to improve learners' motivation and are critical to engaging and immersive experiences in AR game-based learning. With its affordance of enriching real-life education with virtual effects, AR game-based learning has shown its potential to improve recall performance in previous research. However, educators and researchers have concerns regarding the effect of employing fantasy game elements in AR game-based learning, suggesting learning with such elements will add cognitive load for children leading to a lower recall. To explore the effect of AR and fantasy in game-based learning for recalling declarative knowledge, we conducted an experiment involving 98 children participants and 26 adult participants from the Netherlands and China, using our own designed AR game- ChemiKami AR. We used a mixed ANOVA to identify the effect of fantasy and AR on knowledge recall. This study showed that using AR fantasy in game-based learning can improve recall of declarative knowledge and increase learning effectiveness in classroom learning contexts for children. We offer insights and guidelines for designing AR and fantasy experiences that enhance declarative knowledge recall for target groups with different ages, learning capacities, and cultural backgrounds.

1. Introduction

Augmented reality (AR) for learning promises to improve the recall of information because of AR's potential to enhance narrative experiences [1] and enrich the visual qualities of interactions [2], which leads to better recall [3]. The recall of declarative knowledge, knowledge of rules that learners can verbalize and apply, is an essential indicator of effective learning [4]. The effect of AR-based learning has, for example, been investigated on recalling historical information [1], spatial navigation [5], and rehearsal tasks in academic recall [6].

The presentation mode of AR content ranges from practical enrichment of physical contexts, such as text overlays or placement of virtual objects in physical environments [7], to fantastical scenarios featuring virtual factors and colorful scenarios of live interaction with digital representations and their environments. The range of presentation types raises the question: which presentation can encourage learners to recall more?

Educators show concerns that fantasy and playfulness in learning might be irrelevant, diverting too much attention [8], adding too much cognitive load for children [9], and, as a result, rendering AR learning ineffective [10]. However, children may appreciate fantasy, unreal and fictitious settings such as magical stories in game-based learning because fantasy avatars may correspond to their wishful identification [11,12], and fantasy narratives may allow them to immerse themselves in learning in contrast to working through a learning tool [13].

While the use of AR to improve knowledge recall for children seems a promising area of research, educators' concerns are justified and require careful investigation, considering that research has not provided conclusive evidence addressing the effect of using AR and fantasy to enhance the effect of declarative knowledge learning and recall. Previous work has shown that the game genre in game-based learning determines the learning effect [14–17]. Working memory, a cognitive process of storing and operating information temporarily, involves the system that processes visual-spatial, sound, and episodic information [18]. Working memory is one of the determining factors of effective learning [19]. The application of AR is promising for a more effective recall of information by elaborating to-be-learned material that enables multi-modal sensory, including visual, verbal, proprioceptive, and tactile memory [3].

To gain better insights into the effect of fantasy-enhanced AR on the effect of learning and recall, we designed ChemiKami AR—a card-based AR game to help beginners memorize chemical elements. To investigate the effect of fantasy in AR game-based learning on learning and recall of chemical elements, we conducted experiments with 124 participants from three locations, Jan van Brabant College (JVB) in Helmond, the Netherlands, International School Eindhoven (ISE), in the Netherlands,

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https://doi.org/10.1016/j.entcom.2023.100563
Received 4 November 2022; Received in revised form 17 January 2023; Accepted 20 February 2023
Available online 24 February 2023

and Changzhou in China. All participants played the game in AR and a Non-AR baseline, while we varied the setting (fantasy, real-life) of recalling chemical elements between subjects.

Our research aims to support designers with practical guidelines for incorporating AR and fantasy in game-based learning and inspire learners and educators with contemporary instructional approaches to achieve their learning goals.

2. Related work

2.1. AR for education: Benefits and challenges

The application of Augmented Reality (AR), a technology that blends the virtual with the physical, in education has been shown to improve learning motivation and engagement [20] and create a more immersive and pervasive gaming experience [21]. AR provides context-aware learning situations in real environments [22]. It allows participants to perceive complicated spatial connections and the unobservable in real-life settings to comprehend better abstract ideas [23] and can potentially improve recall by facilitating the integration of information [24].

Despite the educational advantages of AR, designers should be aware of technical and pedagogical challenges while designing AR for education [25]. According to Squire & Jan's [26] study, when adequate instruction or guidance for gameplay is absent, students' comprehension of information flow towards devices and the natural world is challenging. When learners have to process too much information from both worlds, facing new technology and unfamiliar settings and tasks simultaneously, the mix of real-world problems and virtual fantasy may be confusing [27].

2.2. Fantasy in Game-based learning

Although designing AR game-based learning faces several challenges, it is promising if game-based learning can stimulate children's inherent need for fun and satisfaction, which enables their intrinsic motivation to learn [28]. Fantasy as a game element represents narrative, visual, or interactive styles that do not exist in the real world [29,30]. Endogenous fantasy, the integration of educational content into fantasy integrally and continuously, can intrinsically motivate learners [31]. Research by Stapleton et al. shows that mixed reality technology like AR and VR can facilitate the suspension of disbelief and engage participants in a rich fantasy experience. They constructed a mixed fantasy continuum for compelling entertainment experiences with mixed reality and fantasy (Fig. 6.2).

Anthropomorphism is one way of intrinsically (or endogenously) integrating fantasy [31]. Anthropomorphism, introducing non-human entities with human traits, has been shown to enhance people's memory of events [33]. Anthropomorphism in literature enables young readers to identify with the character, opening a portal for them to enter the enjoyable world of fantasy [34]. Animation for education also frequently takes the feature of anthropomorphism. For example, "Cells at Work!" and "Once Upon a Time… Life" are two animations that describe human body systems and defensive mechanisms via the stories of various characters that represent different cells or organs in human bodies (Fig. 6.1).

However, as previously stated, designers and educators face the challenge of giving appropriate and suitable guidance for users to approach AR games that facilitate effective learning. Participants need easy-to-use and easy-to-understand interaction contexts with blended virtual fantasy and real-world scenarios. Designers should understand if incorporating fantasy content with AR in learning benefits learning effects or not. Declarative knowledge recall throughout the learning process is an essential indicator of effective learning.

2.3. The role of working memory in education

Working memory refers to a cognitive process of storing and operating information temporarily [18]. In working memory, the storage of declarative knowledge, such as conceptual, propositional, or descriptive knowledge, serves as the foundation of the learning process [37]. An Individual's working memory capacity, the ability to hold information, is relatively constant, usually ranging from 3 to 5 items [38]. With such capacity unchanged, extra information around the essential data to be stored can help individuals compress and memorize information more effectively [39]. In other words, well-designed contexts where learners encode and retrieve information can benefit learners with more recall by putting in the same amount of effort. For example, with the effect of positional specificity, learners can improve their performance of recall. Positional specificity is the recognition of specific spatial or visual patterns associated with which the information was first presented. Besides visuals, other sensational effects could also facilitate the function of working memory.

Baddeley & Hitch developed a multicomponent working memory model consisting of the phonological loop, visuospatial sketchpad, and episodic buffer. The phonological loop, which refers to the temporary storage of sound, is a rehearsal process that is constantly refreshing to

Fig. 6.2. Mixed-fantasy continuum [32].

Fig. 6.1. The animation "Cells at work!" (left) [35] and "Once Upon a Time…. Life" (right) (*Once Upon a Time…Life Official Website*, 2022) [36] employs anthropomorphism toward cells and organs in human bodies.

prevent its decay [40]. The visuospatial sketchpad stores the image and spatial information. Research suggests that high-imageability words are easier to remember than abstract words [41]. The episodic buffer temporarily stores source information coded into a coherent episodic representation [42] (Fig. 6.3).

The procedure of information integration can also be facilitated through AR. Previous research suggests participants are more effective at recall because AR enables multi-modal sensory elaboration, including visual, visuospatial, verbal proprioceptive, and tactile memory [3]. With the potential association between the multi-modal sensory elaboration enabled by AR and the working memory's multicomponent, we are curious about the representation we can design with AR. We wanted to investigate whether AR fantasy in game-based learning can improve declarative knowledge recall.

To explore the effect of fantasy in AR game-based learning on declarative knowledge learning and recall, we conducted a quasi-experiment where we compared three conditions: AR real-life content, AR fantasy content, and a non-AR version as the baseline. We are interested in four research questions:

RQ1. Is AR with fantasy more effective at improving recall than AR with real-life content?

RQ2. How do participants perform with AR in comparison to their recall without AR?

RQ3. After playing with AR, will the recall of the augmented content be activated by content on cards?

RQ4. Do age groups, genders, and locations associate with any difference in the recall?

To answer the research questions, we designed an AR-based learning game, ChemiKami AR, and implemented the experiment settings around the game.

2.4. Design of ChemiKami AR

ChemiKami AR is an Augmented Reality card game for children to learn chemical elements, developed using Unity 3D 2020.2.7F1 and the Vuforia Engine 9.7. With the support of Unity 3D and the Vuforia Engine, the app ChemiKami AR pre-installed on the phone can present a 3D overlay on the screen when a specific pattern is recognized through scanning via the phone's camera. We developed the game with more 3D interactive animations when two specific cards are scanned, using Unity 3D with C#. All the 3D models were created using Blender 2.83LTS and Vroid Studio v0.12. Adobe Photoshop and Illustrator were used to design 2D image targets for cards. There were two languages available: English and Chinese. An English teacher checked the phrasing in both languages. In addition, two designers have the gameplay interaction checked. A chemistry expert and a physical science expert also reviewed the game content.

In chemistry, an element is a pure substance of identical atoms. Atoms are too small to be seen with our eyes [43]. Therefore, students usually know the visual shapes of an element by the compounds or monomers it composes, which come in various forms [44]. For example, there are multiple isomers from the element carbon, with numerous looks, including diamonds, graphite, and more [45]. The uncertainty of elements' visual representations confuses beginners because there is no

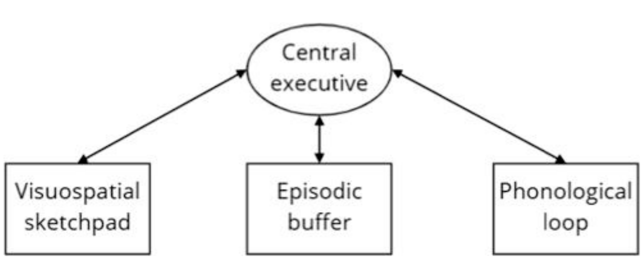

Fig. 6.3. The multicomponent working memory model [42].

visual representation they can refer to when encoding information in their memory process. The absence of representative visual, audio, or story that helps beginners' memorization makes it valuable to design a fantasy avatar representing each chemical element. For example, we designed a character that represents the element Fluorine (Fig. 6.4, left). We are curious whether fantasy can aid in learning and recalling chemical elements and their applications. We designed a real-life setting for the control group, in which elements are represented by one of the shapes of their monomers. For example, Fluorine's monomers are light yellow liquid at extremely low temperatures (Fig. 6.4, middle). The models' shapes and textures in the real-life group are drawn from the book "The Elements: A Visual Exploration of Every Known Atom in the Universe" by Nick Mann and Theodore Gray.

The interaction of the game in the two conditions is similar. In the fantasy condition, when participants scan an element card, they see an augmented overlay of a 3D avatar that introduces itself as an anthropomorphic embodiment of the chemical element. In the real-life condition, when scanning an element card, participants view a 3D representation of the relevant element's monomer while listening to the element's introduction from a background voice on their phones (Fig. 6.5) which is also shown as text on the cards. Participants in either group need to locate the element's associated application from a stack of application cards, e.g., the participant pairs the element Fluorine with its application (Fig. 6.6). A correctly paired scanning triggers animation and completion of the tasks on the application card, while wrongly paired cards trigger no effect. In the case of Fluorine (Fig. 6.6), the snowman stops melting because the air conditioner is functioning when the refrigerant consisting of the element fluorine is added. There are ten game tasks, which include, for example, helping a flat balloon fly with Helium, helping a dizzy fish with oxygen, and more.

We created the game with ten chemical elements to test the maximum number of chemical elements that can be memorized, as people's working memory capacities usually range from 3 to 5 items [38]. We also created a baseline set of non-AR cards with ten different sets of elements and associated applications (Fig. 6.7) to test learners' recall of traditional learning materials without AR and fantasy. Since the baseline was set up to emulate the traditional instruction context, we designed real-life photographs similar to figures from chemistry textbooks. The task stays the same in the baseline setting: identifying a corresponding correct pair for each element card. Participants can see the correct answer from the slides to identify if they are correct.

2.5. The experiment settings

To study the effect of the fantasy setting [Fantasy, Real-life] and the interface setting [AR, Non-AR] (Table 6.1 on recall, participants played either a fantasy-enriched card game or a real-life card game, then did a knowledge test containing ten elements involved in the game. They were also invited to engage in a non-AR baseline version and finish a relevant knowledge test. The ten chemical elements used in the fantasy version were identical to those in the real-life version. Chemical elements in the within-subject interface setting [AR, Non-AR] comprised two different sets of 10 chemical elements to avoid memory effects [46] affecting our results. The sequence effect was also mitigated through a counter-balanced gameplay sequence of the AR games and baseline. The randomization of questions that appeared in the knowledge test is also achieved through Tencent Questionnaire.

2.6. Participants and procedures

A total of 124 participants participated in the experiment. Ninety-eight participants in our target age range were children between 13 and 15 years old, the appropriate age for students to start learning chemistry. Twenty-six participants were adults (between 18 and 84), with an average age of 45, who were not our main targets but could give extra insights into the effect on adolescents and adults. Adult data

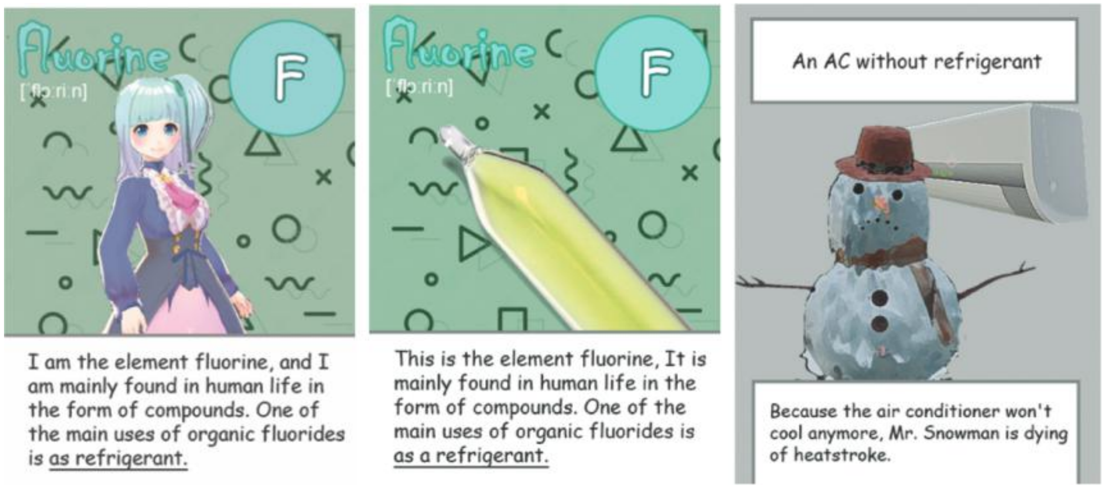

Fig. 6.4. The fantasy element card Fluorine (left); The real-life element card Fluorine (middle); The corresponding application card to Fluorine (right).

Fig. 6.5. Scanning an element card and looking for its application card in the real-life condition.

Fig. 6.6. Correctly paired scanning of Fluorine and its application in the AR fantasy condition.

collection was not intended initially, but many parents of adolescent participants showed an interest in the card game and offered to participate. As a result, we obtained supplemental data from adults around middle age, which can be pilot research for further investigation of designing fantasy for participants of different ages. Since our primary focus is children participants, we only use children's data to answer RQ1, RQ2, and RQ3. We regard adults' data as extended data for answering RQ4. This study was undertaken in two countries, the Netherlands and China. Therefore, we also discuss cultural differences and their effect on learning with AR and fantasy in RQ4.

Our study in the Netherlands was conducted as a class activity for children at two different schools—the International School Eindhoven (ISE) and the Jan van Brabant college (JVB). ISE is an international school where we invited international students (N = 66, 32 self-identified as female, 34 as male) from 4 classes with an average age of 13. JVB is a local school where we invited students (N = 12, 9 of whom self-identified as female, 3 as male) at an average age of 14. Students from both schools had just started learning chemistry.

A second part of the study was conducted in Changzhou, China, with 20 children (average age = 13; 7 self-identified as female, 13 as male). We also conducted the study with 26 adults in Changzhou (average age 45; 19 self-identified as female, 7 as male). We allocated around half of the participants from each location to play the fantasy setting and the baseline interface and the other half to play AR real-life setting and the baseline interface. Due to the local COVID-19 policy in China, it is impossible to carry out the research as a class activity, with data collection covering a full classroom of participants at a time. The experiment was done individually in Changzhou, with data collected

Fig. 6.7. Card pairing in the non-AR baseline condition.

Table 6.1
The experiment settings.

Within-subject factor	Between subject factor AR Fantasy	AR Ordinary
	Baseline	Baseline

from one participant at a time. The consent of participants and their guardians were acquired in advance. The Eindhoven University of Technology ethics review board reviewed and approved the research procedure (ERB2020ID165).

We prepared 10 Samsung Galaxy S8 phones with Android systems for the study at JVB and ISE. Participants first marked the name of elements they already knew from a questionnaire and then started the gameplay. Participants received a set of cards and a phone (if needed) for each round of play and listened to an instruction on two types of cards and the steps of play. Each participant had 10 mins to play the set of the game they were assigned to. After 10 min, experiment assistants collected the participants' cards and devices. Then they asked participants to do the knowledge tests to answer ten single-choice questions, as mentioned in the measurement section, within 5 mins. We encouraged participants to use nicknames while collecting their demographic data to keep the data anonymous. Blanks were to be filled out to collect gender information. We labeled answers like woman, female, and girl as female and conducted the same coding for males for statistical convenience. Additionally, all participants were encouraged to leave comments about the version they played.

The study in Changzhou was conducted one by one. Due to local COVID-19 policy restrictions, we could not access local schools to organize similar class activities as in the Netherlands. All participants' data were gathered in separate rooms at their homes. We used the same android phone, Xiaomi Mix2, and the same sets of cards for every participant. All experiment steps and gameplay time limitations remained consistent with those applied as class activities in the Netherlands (Fig. 6.8). Although we tried to control environmental variables, there were differences between a classroom setting and a private room setting. Therefore, we will reflect on the locations' differences and their potential effect in the later discussion.

Measurements.

We prepared three sets of knowledge tests that assess participants' learning effectiveness. Since individuals were assigned to either AR fantasy or AR real-life conditions, each participant filled in only two sets of questions (one condition and one baseline). Each set contained ten single-choice questions regarding the ten elements they learned from the version they had just played.

To answer RQ3, "After playing with AR, will the recall of the augmented content be activated by content on cards?" We embedded the images they had seen from the element cards in the knowledge test questions. Each participant was randomly assigned five questions with pictures and the other five questions with only text. We compared results between the text questions and the picture questions to address RQ3. Examples of the text (Fig. 6.9) and picture (Fantasy: Fig. 6.10, Real-life: Fig. 6.11) questions are presented below. A participant got one point for each correct response to a question and zero points for each wrong answer.

Fig. 6.8. the experiment set up in Changzhou (left), JVB (middle), and ISE (right).

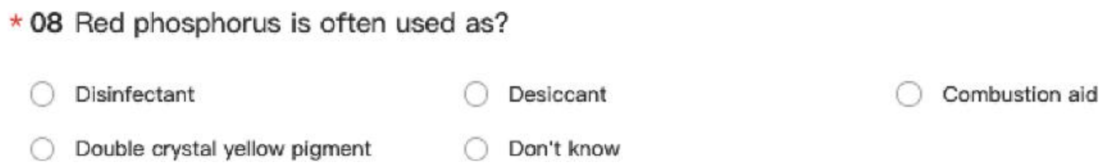

Fig. 6.9. The text question about the element Phosphorus (which remains the same in the fantasy and the real-life condition).

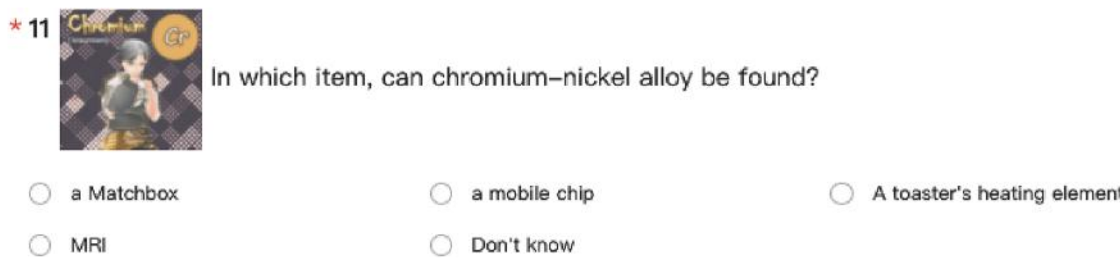

Fig. 6.10. The picture question about the element Chromium (in the fantasy condition).

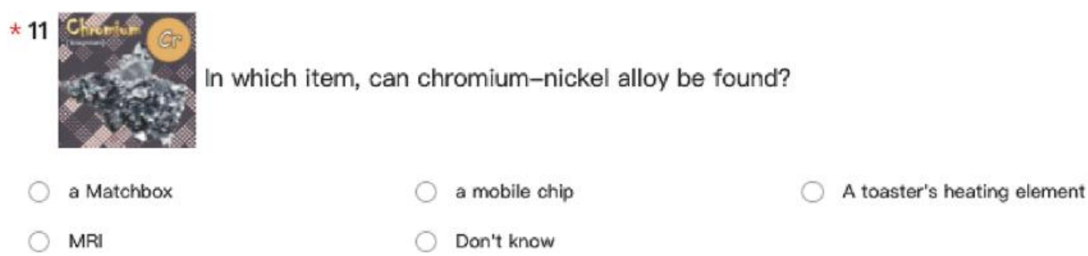

Fig. 6.11. The picture question about the element Chromium (in the Real-life condition).

2.7. Data analysis

We processed our data using SPSS25. Considering our target user groups were chemistry beginning learners, we excluded the data collected from the adult participants at the initial steps of answering RQ1, RQ2, and RQ3. Because we collected data from children at three different locations, we compared the knowledge about chemical elements prior to the study. Adults' recall data was only added to the analysis to compare age groups when addressing RQ4.

3. Results

To answer RQ1 and RQ2, we conducted a mixed ANOVA to test the difference in knowledge tests results, using the fantasy setting "Fantasy or Real-life" as the between-subject factor, the interface setting "AR or Baseline" as the within-subject factors, and the total scores and number (s) of known element(s) as the dependent factors.

As indicated in Table 6.3, there was a significant main effect of the Fantasy setting "Fantasy or Real-life," $F(1,96) = 9.08$, $p = 0.003$, $\eta p2 = 0.086$ on the knowledge test scores (Table 6.2). The scores for the knowledge test in AR fantasy ($M = 7.53$, $SD = 1.58$, $N = 53$) and AR real-life ($M = 6.4$, $SD = 2.10$, $N = 45$) conditions were significantly different. These findings imply that the fantasy setting in AR game-based learning influences recall. Specifically, our findings indicate that AR fantasy is more successful in improving recall than the design with AR real-life elements. There was no significant effect from within-groups or between-group factors on the scores of prior knowledge tests, suggesting children participants had similar prior knowledge of chemical elements in different groups.

RQ2.How do participants perform with AR in comparison to their recall without AR?

As indicated in Table 6.3, the mixed-ANOVA showed a non-

Table 6.2
Descriptive data.

DV	Interface	Fantasy Setting	Mean	Std. Deviation	N
Previous Knowledge	AR	Fantasy	4.04	2.369	53
		Real-life	4.31	2.391	45
		Total	4.16	2.371	98
	Baseline	Fantasy	4.19	2.466	53
		Real-life	4.04	2.383	45
		Total	4.12	2.417	98
Knowledge Test	AR	Fantasy	7.53	1.576	53
		Real-life	6.4	2.104	45
		Total	7.01	1.913	98
	Baseline	Fantasy	7.15	2.143	53
		Real-life	6.02	2.718	45
		Total	6.63	2.476	98

significant effect for the main effect of the Interface Setting ($p = 0.094$). No interaction effect ($p = 0.999$) was found in the mixed two-way ANOVA test when analyzing with our target group ($N = 98$). The result suggested no difference in the effect of learning and recalling declarative knowledge between AR games and baseline.

RQ3. After playing with AR, will the recall of the augmented content be activated by content on cards?

To identify whether AR has an effect on activating the recall of the augmented content when participants see the card image alone, we compared participants' performance with picture questions to their performance with test questions in each game. The results indicated that with AR fantasy, participants scored better on image questions ($M = 4.06$, $SD = 0.989$) than on text questions ($M = 3.64$, $SD = 1.002$) ($t(52) = 2.59$, $p = 0.012$), implying that AR fantasy potentially affected the recognition of memory. No such effect was found in AR real-life group.

Table 6.3
Mixed two-way ANOVA with the fantasy setting (Fantasy/ Real-life) as between subject, the interface setting (AR /Non-AR) as the within-subject variable.

DV	Source	SS	F	P
Prior Knowledge	Interface Setting	0.163	0.196	0.659
	Fantasy Setting	0.203	0.019	0.891
	Interface Setting * Fantasy Setting	2.122	2.553	0.113
Knowledge Test	Interface Setting	6.939	2.865	0.094
	Fantasy Setting	**61.988***	**9.082**	**0.003**
	Interface Setting * Fantasy Setting	2.14E-06	0	0.999

DV = Dependent Variable, SS = Sum of Squares, *$p < 0.05$.
RQ1. Is AR with fantasy more effective at improving recall than AR with real-life content?

However, we observed that participants who participated in the real-life baseline group scored higher with image questions ($M = 3.36$, $SD = 1.50$) than answering test questions ($M = 2.82$, $SD = 1.50$); $t(44) = 2.67$, $p = 0.011$, suggesting real-life picture without AR can also help recall.

RQ4. Do age groups, genders, and locations associate with any difference in the recall?

Since this study was conducted across regions and with different age groups, we examined if the results varied according to participants' ages, genders, and cultural backgrounds. We included adults' data and extended the mixed ANOVA model originally constructed the interface setting with "AR or Baseline" as the within-subject component and the fantasy setting with "Fantasy or Real-life" as the between-subject factor, incorporating additional between-subject variables, including age groups, genders, and locations. The results suggested there was a significant effect of location, $F(2, 116) = 11.05$, $p = 0.000$, $\eta p2 = 0.160$, a significant interaction effect of "Fantasy or Real-life" * "AR or Baseline" * location, $F(2, 116) = 3.21$, $p = 0.044$, $\eta p2 = 0.052$.

We found no significant effect by gender and age groups. However, we spotted a significant effect of the within-subject factor, the interface "AR or Baseline," $F(1, 116) = 10.51$, $p = 0.002$, $\eta p2 = 0.083$, suggesting that participants from all ages with AR recall more than with their baseline, which was insignificant when analyzing children's data only. There was also a significant interaction effect of "Fantasy or Real-life" * "AR or Baseline" $F(1, 116) = 4.56$, $p = 0.035$, $\eta p2 = 0.038$. The between-subject factor "Fantasy or Real-life," which was significant in children's data, becomes insignificant when including adults' data.

To further investigate the effect of adults' on our study results, we applied Bonferroni-corrected pairwise comparisons. The result suggests that adults scored significantly higher with fantasy AR than with non-AR baseline ($p = 0.01$). The results show no statistically significant differences between adults' recall with real-life AR and non-AR baseline and no statistically significant differences between their recall with fantasy AR and real-life AR.

To further compare children's recall between different locations, we conducted a Bonferroni-adjusted pairwise comparison, excluding adults' data in the comparison. Pairwise comparisons suggested that participants from Changzhou scored significantly higher than participants from JVB in almost all cases (Fantasy condition, AR: $p = 0.054$, baseline: $p = 0.000$; Real-life condition, AR: $p = 0.005$). Additionally, in the Real-life condition, participants from Changzhou scored significantly higher than participants from ISE (AR: $p = 0.011$, baseline: $p = 0.020$). Participants from ISE scored significantly higher than participants from JVB in the baseline ($p = 0.001$).

In terms of the effect of our design on participants' recall, we found that JVB participants performed much better in AR fantasy than their baseline ($p = 0.008$). Participants from ISE scored significantly higher with AR fantasy than with AR Real-life ($p = 0.003$) (Fig. 6.12) (Table 6.4).

4. Discussions

4.1. Result summary

We examined the influence of AR and fantasy on learners' recall of declarative knowledge in this study. We gained the following insights:

- For children, design using fantasy with AR was more effective in enhancing recall than designing AR with real-life contents of the learning material.
- Children did not demonstrate a substantial difference in recall between AR and baseline conditions.
- We discovered that adding photos as supplementary information improved children's recall in baseline and the AR fantasy condition. Potentially the recall of the augmented content was activated by content on cards after playing with AR
- We found adults perform differently from children. Adults' recall was affected by the use of AR. With AR, adults scored better. Children's recall performance was determined by whether the AR game

Table 6.4
Descriptive data from different locations in the form of M (SD).

		ISE	JVB	Changzhou
Fantasy	AR	7.54 (1.72)	6.20 (1.10)	8.00 (1.00)
	Baseline	7.14 (1.93)	3.60 (1.67)	8.54 (1.05)
	n	35	5	13
Real-life	AR	6.23 (2.13)	5.43 (0.54)	8.14 (2.19)
	Baseline	5.68 (2.59)	5.71 (3.20)	7.86 (2.41)
	n	31	7	7

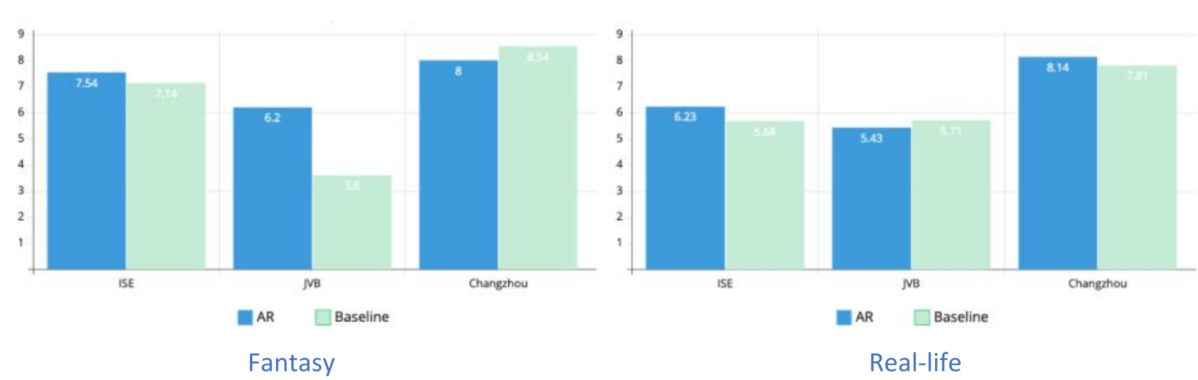

Fig. 6.12. Children participants' mean scores in the fantasy condition from three different locations. (left) Participants' mean scores in the Real-life condition from three different locations. (Right).

featured fantasy or real life. Children performed better when exposed to fantasy in AR game-based learning.

Children in Changzhou performed well in all cases. Their recall was not influenced by our design. ISE students learned more effectively in AR with fantasy representations than in real-life materials. JVB students gained significant improvement over baselines after playing the AR fantasy version.

In general, AR and fantasy game components can aid descriptive knowledge recall. However, the influence of AR and fantasy on recall depends on how individuals encode information, which varies by age group and cultural background.

4.2. Result interpretation

We try to explain our findings by analyzing the influence of AR fantasy on game-based learning and how it supports the cognitive process of recall. We also try to explain the difference between age groups and locations through further analysis of different user groups.

There are a few explanations about why young participants performed better with AR fantasy than with AR real-life. In our AR fantasy version, we used anthropomorphism, turning the chemical elements and their application into human forms and magical scenarios. The anthropomorphic fantasy version may connect an abstract concept to a visualized role, with a plausible story and identifiable sounds that AR strengthen. Additionally, AR fantasy brings stronger immersive and autonomous participants' experiences through imagination [47]. Engaging imagination in learning can positively affect memorization recall [48], which is further enhanced by AR fantasy content, activating a vivid memory [49].

Another reason could be the motivational effect of fantasy. The AR fantasy version features avatars and settings with magic and supernatural elements, bringing a more enjoyable game-based learning experience, especially for young participants [50]. According to Hoffman & Schraw's [51] work, motivational beliefs may enhance learning effectiveness as working memory demands grow. Additionally, previous research indicates that working memory functions as a mediator between children's anxiety and academic achievement [52], implying that effective learning is about memorization with a joyful learning experience. AR Fantasy provides contexts that engage participants in a relaxing and enjoyable atmosphere, which is beneficial for reducing anxiety and frustration during a heavy memorization process, leading to better academic performance.

In our case, AR attaches stories, visual representation, and sound to physical objects (Frohlich & Murphy, 2000), the cards. The recall of attached virtual information is theoretically feasible by activating the position-specific effect when participants are exposed to the initial location or objects where information is presented. Our finding indicates that young participants scored significantly higher with picture questions than text questions with AR fantasy. In contrast, there was no such difference with AR real life. This finding suggests AR fantasy may be better at triggering a position-specific effect that inspires participants' imaginations and recall of the virtual contents from the physical objects than AR real-life. However, we also found participants in their baseline scored higher with the picture question than with the text questions. The finding indicates that questions accompanied by images offer extra information for memory recognition, which may also influence participants' recall in the AR versions. To evaluate if AR fantasy enables a stronger recall, we need to collect more targeted data relating to the encoding and retrieving of information during their memory process.

We find that performance of recall varied by age group. Young participants who grow up with digital technologies and gameplay are more accommodating to the AR application [28]. Therefore, the novelty influence of AR game-based learning on recall doesn't influence them as much as it does on adults. It is also worth mentioning that students spend their days learning in classrooms and are frequently required to memorize textbook content for exams, which may suggest that their baseline recall is already quite high. The positive effect of AR is relatively not strong in terms of improvement from students' baseline. The adults in our situation, mainly in their middle ages, had been absent from the classroom and test assessments for an extended period. It is reasonable that their memorizing techniques and test-taking skills have declined, having a lower baseline recall, which offered more space for AR to have an effect.

Through the result that no main effect of fantasy was found among adults' learning and recall, we found connections to previous research regarding fantasy settings for different age groups. Earlier studies suggest that fantastical aspects are a substantial motivator for younger generations but do not effectively drive senior participants [53]. However, the pairwise comparison demonstrates that only in the AR fantasy condition did the adults enhance their recall from baseline. Such results might suggest that AR fantasy still has a positive effect on recall. It is possible that the fantasy genre used in our design, which was intended to assist young participants, did not correspond to the genres favored by the majority of adults. Adults also like fantasy in films, books, and games. The design of fantasy should be tailored to their interests in order to improve recall.

We also find that recall varied by location. Participants at ISE are international students, and they study chemistry in English. They possess sufficient learning capacities, and the fantasy version improves their motivation and fosters a vibrant classroom environment that encourages them to learn more. The English version of chemistry is more challenging for native Dutch participants at JVB. Under such circumstances, AR has a stronger influence. We noticed that participants from Changzhou, China, who performed significantly better than participants from the other two locations, showed no difference between game versions. Despite many of them leaving feedback, claiming they like the fantasy version or the idea of learning with AR games, their recall performance is not influenced by the factors of AR or fantasy. This phenomenon may be partly explained by the method used to collect data from Changzhou participants, which is one-by-one, resulting in participants' greater focus and recall in each case. Another reason may be, as Biemans & van Mil [54] found in their research on the learning styles of Dutch and Chinese students, that Chinese students have a stronger test-directed orientation when learning. This orientation is related to Vermunt's reproduction-directed learning style [55]. Such a learning style includes memorizing and rehearsing key information the learner selected from the learning material [56], possibly leading to an excellent performance in related tests regardless of conditions. However, this does not indicate that such learners do not appreciate fantasy contexts or the implementation of novel technologies like AR in learning. On the contrary, fantasy and AR would create more alternative learning strategies or motivators for learners than test-oriented learning styles [57].

4.3. Design guidelines

We suggest several design guidelines applicable to AR fantasy in game-based learning by evaluating the research outcomes. We discover that applying fantasy enhances recall more than using real-life settings in an AR learning environment, implying that well-designed fantasy may transform redundant information into a facilitator for processing information. We can draw a few insights into how to construct fantasy effectively from our study.

Anthropomorphism with a visualized concept, narrative representations, and audio feedback creates plausible and unique virtual fantasy contexts for memorization processes. Likewise, we recommend recognizable AR fantasy representations connecting to these three aspects. Since AR fantasy settings can aid in recalling the virtual information while perceiving the physical content, learning experiences can be designed to switch between playing with physical materials with augmented layers and playing without augmented layers to engage the participants' imagination throughout their memory process. Fantasy play may increase students' motivation to study and may result in more effective learning. For designers, it is vital to understand the target user groups' fantasy orientation [58] and the forms of fantasy they appreciate.

Noticing that participants appreciate fantasy differently by age group and location, we recommend that designers adjust the application of AR and types of fantasy for various target groups. For example, designers could apply AR technology to adults with playful content according to their preferences. The integration of AR and fantasy should also be adjusted according to the target groups' capabilities and learning styles. We suggest applying AR to deepen understanding of the concept when the content to be memorized is too complicated for the learners. If the learning of abstract knowledge influence students' motivation, AR fantasy can be employed to encourage students to learn autonomously and improve their performance on recall. For students with reproduction-directed learning styles, the application of AR and fantasy should focus on inspiring them further in terms of knowledge application and creativity.

4.4. Limitations and future work

There are several limitations in our design of the study. We experimented and collected data differently in different locations, depending on the local COVID-19 policies. Some phenomena might also be attributed to data collecting methods in which data from Changzhou were mostly gathered individually. Participants sitting together in a classroom and participating in the experiment simultaneously could have different engagements, which might have had an impact on the different outcomes. Additionally, adults' data were only collected in Changzhou. Although adults are not our research focus, a further collection of data from other locations would provide more solid results on the influence of age. It was indicated that the recall of the virtual content is activated by content on cards after playing with AR. A concrete conclusion regarding this, however, requires further investigation.

Furthermore, real-world learning environments and the demands put on students' memory are often more complicated than our experiment settings. Additional long-term research may help us understand how AR and fantasy benefit students in a range of diverse contexts. Our results, taken along with earlier research, show a possible pathway for recall enhancement triggered by AR fantasy through increased motivation. It is a potential direction to continue research on the relationship between motivation and recall in future work.

5. Conclusion

This study provides evidence that using AR fantasy in game-based learning can increase recall of declarative knowledge and increase learning effectiveness for children. We believe that AR fantasy can activate the recall of virtual overlays from physical objects. On the other hand, adults react differently from children, who demonstrate an improvement in recall with AR regardless of whether fantastical or real-life components are used. We also find there is a difference between students' recall performance with AR fantasy caused by different locations and cultural backgrounds.

ChemiKami AR benefits both learners by providing an engaging and effective game-based learning experience. The empirical results on the influence of fantasy and AR on recall may drive more exploratory research to exploit the potential of AR and game-based learning. We suggest several design guidelines for developing AR learning apps and employing fantasy in game-based learning. We hope this research helps designers to employ fantasy game elements in learning. Hopefully, this work can inspire more designers to create attractive game-based learning experiences that can compete with entertainment games and effective game-based learning experiences that engage learners with enjoyable, meaningful learning experiences.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

Acknowledgments

We would like to express our deep and sincere gratitude to Angela Gedeller and Sandra van den.

Berg who enabled and helped conduct our experiment in ISE and JVB. We are grateful to Huaqin.

Zhao, who gave support in the conduct of the experiment in Changzhou. We would like to thank China Scholarship Council to fund this project (grant ID: 201806790091).

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