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ABSTRACT

This study attempted to develop and compare two Augmented Reality (AR) educational game systems for third graders to learn English vocabulary in free and situated surroundings. One system was developed based on a self-directed learning approach which did not restrict the learning sequence, while the other was based on a task-based learning approach which limited the learning sequence. The flow experience, cognitive load, foreign language learning anxiety, and learning effectiveness of the students with different learning styles (i.e., serial or global) were assessed. The results showed that the students using the self-directed or task-based AR educational game system had similar and high learning effectiveness, although those using the self-directed system revealed higher flow experience. However, the students with a serial learning style had lower mental effort and foreign language learning anxiety regardless of using the self-directed or the task-based AR educational game system. It was found that the challenge and control of the system conformed to the students' proficiency. The learning objects (e.g., pen, pencil, book, chair, desk, eraser, ruler, etc.) did not have a restrictive learning sequence. Providing free learning steps was preferable, and restricting which step to begin with was not necessary. This

study confirms that the mental efforts of students are greater when they experience more learning anxiety at the same time; however, it is not the case that lower learning anxiety and mental effort is better for learning. On the contrary, a little learning anxiety and mental effort, but not too much, is helpful for learning.

Keywords: elementary education, evaluation of CAL systems, interactive learning environments, media in education

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ABSTRACT

This study attempted to develop and compare two Augmented Reality (AR) educational game systems for third graders to learn English vocabulary in free and situated surroundings. One system was developed based on a self-directed learning approach which did not restrict the learning sequence, while the other was based on a task-based learning approach which limited the learning sequence. The flow experience, cognitive load, foreign language learning anxiety, and learning effectiveness of the students with different learning styles (i.e., serial or global) were assessed. The results showed that the students using the self-directed or task-based AR educational game system had similar and high learning effectiveness, although those using the self-directed system revealed higher flow experience. However, the students with a serial learning style had lower mental effort and foreign language learning anxiety regardless of using the self-directed or the task-based AR educational game system. It was found that the challenge and control of the system conformed to the students' proficiency. The learning objects (e.g., pen, pencil, book, chair, desk, eraser, ruler, etc.) did not have a restrictive learning sequence. Providing free learning steps was preferable, and restricting which step to begin with was not necessary. This study confirms that the mental efforts of students are greater when they experience more learning anxiety at the same time; however, it is not the case that lower learning anxiety and mental effort is better for learning. On the contrary, a little learning anxiety and mental effort, but not too much, is helpful for learning.

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1. Introduction

Many studies have pointed out that different types of knowledge should be connected on the basis of proper stimulations so as to become meaningful knowledge (Knobelsdorf, 2015). Knowledge is learned, internalized and applied so as to achieve value and meaning in the situated learning context. The learning scenario for English as Foreign Language (EFL) learners is of vital importance (Golonka, Bowles, Frank, Richardson, & Freynik, 2014). Situated learning could simulate an authentic or virtual condition which the learners may confront abroad or in their daily life (Anderson, Reder, & Simon, 1996). The feature of situated learning is to provide warm-up practice which can achieve the effects of transferring learning from the teacher-centered to the student-centered approach. The learners should combine and apply their knowledge with the new information just gained in the situation (Suchman, 1987). In this way, learners experience how to apply the English they have learned, and understand the essentials for learning English (Preston et al., 2015). Another feature of situated learning is that learners can organize what they have learned to achieve knowledge-internalization. Situated learning has not only improved the traditional one-way teaching, but has also allowed students to actively observe and look for information in the environment by themselves. Finally, the students experience how to use English properly in realistic conditions or solve problems in certain situations using the knowledge they have learned and organized. As a result, the role of teachers has changed from being instructors to advisors or facilitators giving opinions, scaffolding, or providing feedback (Cobb & Bowers, 1999).

Although situated learning provides students with a virtual environment which mimics the real world, directly using Augmented Reality (AR) in the real world could more effectively support students in achieving the learning objectives. A previous study mentioned three AR features, namely the integration of the virtual and real worlds, interaction in real time, and operation in three-dimensional (3D) space (Azuma, 1997). Figure 1 shows how AR extends the real world. A meaningful learning activity emphasizes that students can apply their knowledge and skills in the real world, and teaching should connect with real life experience. When AR is effectively applied in education, it can increase students' learning interest and concentration (Wu, Lee, Chang, & Liang, 2013; Zhang, Sung, Hou, & Chang, 2014).

Figure 1. Milgram's Reality-Virtually Continuum (Milgram & Kishino, 1994)

This study explored the cognitive load, flow state, foreign language learning anxiety and learning effectiveness of students who used AR educational games to assist their language learning based on self-directed learning and task-based learning approaches. Following is a review of the studies related to cognitive load, self-directed learning, task-based learning, learning styles, flow state and AR.

2. Literature Review

There is a real need for teachers or instructional designers to design learning activities for AR (Kesim & Ozarslan, 2012). Scholars have identified some features and affordances of AR applications for learning, such as ubiquitous and situated learning and learners' senses of presence and immediacy. They have classified three different learning approach characteristics which place emphasis on engaging learners in different roles, learners' interactions with the physical locations, and the design of

learning tasks (Wu et al., 2013). Scholars have noted that formal learning should be established from the students' embodied experiences of the world (Niebert, Marsch, & Treagust, 2012); it is therefore necessary to place the students in a situated environment based on the design principles of embodied cognition and learning (Wilson, 2002). For example, scholars have conducted embodied learning by providing students with a tangible user interface (TUI), and found that the participants had better learning performance in comparison with those using a mouse (Skulmowski, Pradel, Kühnert, Brunnett, & Rey, 2016). Other scholars have employed embodied interaction with mixed reality simulations for learning physics, and indicated that both learning and affective engagement were enhanced due to the embodied simulations (Lindgren, Tscholl, Wang, & Johnson, 2016). When AR games are designed for particular pedagogical purposes, especially self-directed learning, or task-based learning, it can also potentially motivate and strengthen the authentic practice of the skills and abilities needed in today's workplaces such as information management, problem solving or reflection skills (Schrier, 2006).

2.1. Self-directed learning and task-based learning

This study designed one quest-based AR educational game for self-directed learning and another for serial task-based learning, both with the same learning goals. Self-directed learning is one of the 21st century core competences, and its practice is able to support lifelong learning in the future, not only to be used within AR learning environments. In domain-oriented design environments such as the language learning domain, AR educational games designed based on self-directed learning allow learners to engage in the game play at their own pace, and solve problems with contextualized support (Fischer & Scharff, 2010). The learners were free to choose any target to learn at their own pace. When the AR system provides the individual

student with immediate feedback on his or her progress, self-paced and self-directed learning can occur (Chen & Tsai, 2012).

Scholars have indicated that task-based learning has been introduced into some AR applications (Wu et al., 2013). Moreover, some scholars have noted that designing learning technologies around the experience of accomplishing a task such as navigating a path was valuable for leading to significant learning gains, higher levels of engagement and more positive learning attitudes (Lindgren, Tscholl, Wang, & Johnson, 2016). If students are confronted with a series of tasks, they have to learn step by step in the process of completing each task. Some scholars have also integrated a problem-based situation and game-based learning in the design of tasks and activities applying AR (e.g., Squire & Klopfer, 2007).

However, different learning material designs create different amounts of mental load, and different learning approaches or instruments result in varying mental efforts. Because two AR educational games based on two different learning approaches were designed in this study, the cognitive loads should be considered. The following section provides a review of the literature related to cognitive load.

2.2. Cognitive Load

Students who apply AR in their learning may be cognitively overloaded by the large amount of information they encounter (Wu et al., 2013) when they have to use multiple technological devices to complete the tasks. Therefore, the current study explored the cognitive loads the students had to bear when they used the AR educational games for foreign language learning based on self-directed learning and task-based learning.

Much research has explored how knowledge forms in the human brain after learning. Previously, scholars proposed that knowledge is stored in the long-term

memory in the form of schema constructions. When an individual receives new information, that information is automatically schematized (Shiffrin & Schneider, 1977). The new information element is categorized according to various uses and functions, and different schema are created for each element (Chi, Glaser, & Rees, 1982; Sweller, Van Merrienboer, & Paas, 1998). Schema construction can help with the recognition of features of homologous objects. For example, no two leaves are exactly the same, but we can recognize if they fall from the same tree. Therefore, schema construction not only helps with the transfer of the new stimulation to long-term memory, but also reduces working memory load. Cognitive load occurs when much more new information is received than the maximum loading of working memory can cope with in a short period of time.

Cognitive load can be divided into three categories, intrinsic cognitive load, germane cognitive load, and extraneous cognitive load. Intrinsic cognitive load tends to result from the learning materials. Performing several low-element interactivity tasks would cause low intrinsic cognitive load, because the working memory can process each element successfully. However, high intrinsic cognitive load is accumulated quickly when the brain is dealing with high-element interactivity tasks. The working memory has to process all of the related tasks, code them to the proper schema, and assign them to the related memory area (Gerjets, Scheiter, & Catrambone, 2004; Sweller et al., 1998). Extraneous cognitive load is caused by inadequate instructional design which is not helpful to the students' schema construction. Extraneous cognitive load should be reduced by properly organizing the new knowledge and transforming its presentation (Shih, Chuang, & Hwang, 2010). Studies have suggested that, when the level of the essential cognitive load and extraneous cognitive load are acceptable for working memory, teachers can guide students to perform the learning activities to acquire new knowledge. Those activities increase

the germane cognitive load, but they also improve the completeness of the schema construction, and promote the application of the new knowledge (Sweller et al., 1998).

Mental effort is mainly caused by the external environment. The more complicated the learning task is, the more mental effort is required to perform it. A noisy environment also causes greater mental effort (Kirschner, 2002). If cognitive load is analyzed based on the learner-based dimension, it is regarded as mental effort. Both mental load and mental effort affect learning performance. When the overall loading does not exceed the highest endurable degree of cognitive load, students can maintain good learning performance using a strategy which decreases their mental load while increasing their mental effort (Kirschner, 2002; Sweller et al., 1998). Therefore, the two factors, learning performance and mental load, cannot be used to directly perform correlative analysis for cognitive load because mental effort should also be taken into consideration. The result of combining mental effort and learning performance is the best way to measure instructional efficiency. Lower mental effort with higher performance is the most efficient (F. Paas, Renkl, & Sweller, 2004; Fred GWC Paas, Van Merriënboer, & Adam, 1994; Sweller et al., 1998). If the research method provides the students with different learning environments, new data including mental load, mental effort, and learning performance should be collected for triangulation analysis, so as to capture the true diversity of instructional efficiency (Kirschner, 2002).

However, students have diverse learning styles. Previous studies have pointed out that students receiving the same treatment do not always exhibit similar learning performance (Hsu, Hwang, Chang, & Chang, 2013). One of the main reasons is that students have their own learning preferences. The following sections explore the effects of learning style as found in several e-learning studies.

2.3. Learning styles

Many scholars have confirmed the effects of learning style on learning performance (Balakrishnan & Gan, 2016; Felder & Henriques, 1995). The concept of learning style originated from the cognitive styles in psychology, which identified the diversity of individual cognitive features; meanwhile, scholars have attributed the individual differences in higher education to learning styles (González, Mendoza-González, Rodriguez-Martinez, & Rodríguez-Díaz, 2016). To achieve better learning effectiveness, other scholars have pointed out that teachers should not assume that all students have an identical way of learning, but should prepare adaptive instruction to fit the different preferences or demands of their students (Hawk & Shah, 2007).

The current study adapted the Index of Learning Styles (ILS) Questionnaire consisting of four dimensions, each including 11 items, to distinguish each student's learning style from two contrary styles (Solomon & Felder, 1999). The four style dimensions and the contrary styles in each dimension are active/reflective, visual/verbal, sensing/intuitive and sequential/global (Felder & Spurlin, 2005). The 'sequential/global' dimension was employed in this study to clarify whether the students with a sequential learning preference or those with a global learning preference learned better and concentrated more in each AR educational game system in this study.

There have been few studies which have probed the correlations between the cognitive loads and flow state of students, although some have explored the flow experience of students when learning with some digital learning systems, as discussed in the next subsection. In this study, as well as considering their cognitive load, the

flow state of the students who used the AR education games for learning English was also explored.

2.4. Flow state

Flow state refers to an optimal experience which happens in certain activities (Csikszentmihalyi, 1975b). When an individual is immersed in a flow state, he or she will experience high concentration, time passing rapidly, a balance between challenge and skills, and positive enjoyment (Barzilai & Blau, 2014). Therefore, when a student has a high flow state, he or she will feel excited, ecstatic and highly efficient during the learning process. It is worth exploring the flow states of students when they conduct different AR game learning activities.

Csikszentmihalyi indicated that flow is motivated by matching the proper challenge with individual capability during the activity. Conversely, if the challenge posed by the activity is too easy or too hard, a flow state will not occur (Csikszentmihalyi, 1990, 2000). Flow is defined as a temporary and subjective experience, which is the reason why people like to do some activities repeatedly (Csikszentmihalyi, 2000; Webster, Trevino, & Ryan, 1993). At first, Csikszentmihalyi pointed out four features of flow, namely control, autotelic design, narrowing of consciousness, and self-forgetfulness. A successful flow-inspired activity will let the participant feel that he/she can control what will happen next, and there is a target which needs to be achieved (autotelic design). The target should match the participant's ability. The event should not waste too much of the student's consciousness, but should help the student achieve centralizing and narrowing of the consciousness. The narrowing of the consciousness further leads to the reaction of self-forgetfulness (Csikszentmihalyi, 1975b).

Researchers who have focused on the studies of human-computer interaction

experience have pointed out four factors promoting flow: control, attention focus, curiosity, and intrinsic interest (Trevino & Webster, 1992; Webster, Trevino, & Ryan, 1994). Recently, the research on mobile-assisted game-based learning has found that the quality of flow inspired by games with different levels of difficulty was the same as long as the level matched the capabilities of the individual students (Bressler, 2014). Scholars have concluded five factors which impact the flow state of students using mobile-assisted game-based learning. Firstly, the students had the power of control during the game. Secondly, they could modulate their characters in the game to tally with their own self-image. Thirdly, it was easy for them to stop or close the game when there was interference from the real world. Fourthly, the system would not delete the historical records of the students when the game was played repeatedly. Fifthly, the instructions in the game were clear and easy to understand (Chou, Hung, & Hung, 2014).

2.5. Foreign Language Learning Anxiety

The Foreign Language Classroom Anxiety Scale (FLCAS) was first developed by Horwitz, Horwitz and Cope (1986). They were concerned about the learning anxiety of students as many students fail in foreign language learning due to the high anxiety levels which have been verified to exist in the classroom (Yang & Chen, 2007). For example, previous studies have explored the effects of many human factors such as gender, achievement, or age on foreign language learning anxiety, and it was found that there were no significant gender differences in foreign language anxiety (Gopang, Bughio, & Pathan, 2015), that there was a significant negative relationship between students' foreign language anxiety and their English achievement (Gerencheal & Horwitz, 2016), and that children experience higher levels of anxiety as they get older (Er, 2015). However, few studies have explored the effects of learning styles on the learning anxiety of students.

Scholars have pointed out that employing technology to assist language learning is helpful for students to have lower anxiety and more positive attitudes towards English vocabulary acquisition in comparison with conventional instruction (Alemi, Meghdari, & Ghazisaedy, 2015). In countries where English is a foreign language, in order to provide the learners with situated English environments, utilizing computer- or mobile-based applications in the classroom is the second-best choice after having access to a native speaker (Yang & Chen, 2007). Scholars have also indicated that media facilitate language learning by reducing anxiety (Hwang, & Huang, 2010). Therefore, in this study, we were interested in the effects of different AR system designs on learning anxiety, where the learning material was augmented with real situations or with the classroom surroundings.

2.6. Research questions

In this study, a task-based learning AR educational game and a self-directed learning AR educational game were developed to situate students in real-life contexts for English courses. In addition, an experiment was conducted to explore the effects of the proposed approaches on students' learning effectiveness, flow state, learning anxiety, and cognitive load. The research questions are listed as follows.

(1) Which of the task-based learning and the self-directed learning AR educational game caused a higher flow state? What was the flow state of the students with different learning styles in each AR educational game?

(2) Which of the task-based learning and self-directed learning AR educational games caused lower cognitive load? What was the cognitive load of the students with different learning styles in the AR educational game systems?

(3) Which of the task-based learning and self-directed learning AR educational games caused higher learning anxiety? What was the degree of learning anxiety of the students with different learning styles in each AR educational game?

(4) Did both of the AR educational games result in high learning achievement? What was the learning effectiveness of the students with different learning styles in the AR educational game systems?

3. Method

3.1. System development of the AR educational game

The AR educational game systems developed for this study aimed at helping third-grade students in an elementary school to spell and learn English vocabulary in real-life situations. There are two English AR learning systems each containing the same vocabulary learning material and both with seven situational stations and checkpoints named the pen station, the pencil station, the eraser station, the ruler station, the book station, the chair station and the desk station. Some screenshots of the AR application are shown in Figure 2.

Figure 2. Six screenshots illustrating the vocabulary AR game

Because the learners were very young students and were English language beginners, each checkpoint was designed for only one vocabulary item. It was expected that the students would remember the usage context of each vocabulary item after playing the AR educational game. The two systems were designed based on different learning approaches, so it was further examined which learning-style students preferred using and learning with which system.

One system was designed based on the self-directed learning approach. The

students were free to choose which situational stage or challenge to begin with. The AR educational game system recognized which situational stage they were confronted with and provided them with contextual learning material and a checkpoint. They had to pass the seven challenges with the assistance of the learning material which was the information provided in the AR game. In other words, the self-directed AR educational game allowed the students to freely select the sequence of the learning targets. They could re-choose a learning target if they failed to solve the test for the present learning target two times. They were then free to choose the same target or a new one. No matter what sequence they learned in, they had to compete to learn all the situated English distributed in the surroundings with the support of the augmented application on the Tablet PC.

The other system was designed based on the task-based learning approach. The students who learned with the task-based AR educational game had to complete the challenges task by task until all stages had been completed. They were not free to choose which situational stage to begin with, but were guided by the system to face each challenge, learning content and checkpoint. In other words, the students followed the arrangement of the task sequence. They had to solve the situated tasks according to the target guided by the augmented application on the Tablet PC. If they did not solve a task, they could not go on to the next one. They had to learn the AR material and be sufficiently proficient to pass the test at the end of each learning target.

The framework of the two systems is shown in Figure 3. The two systems have the same log-in interface and the same checkpoint after each AR learning target, but different learning procedures.

Figure 3. System Framework of the Self-directed and Task-based AR educational games

At the end of each learning target, there was a test which was a spelling game. However, the small-screen device was not convenient to type words, especially for young children. Therefore, the letters of the word were shown in random sequence, and the children used their finger to move the letters so they did not need to type the word using the virtual keyboard; this is shown in Figure 4. When the student placed the letters in the correct sequence and confirmed the spelling, the system assessed whether the word was spelt correctly. If the student's answer was wrong, the two systems had different reactions as mentioned in the previous paragraph. The system based on the self-directed learning approach would give the students a hint when they spelled the word wrong the first time. If they spelled it wrong twice, they had to re-choose a learning target, which could be either the same one or a different one. The students could see a circle under those learning targets which they had successfully completed, a blank under those which they had not yet done, and a cross under those which they had failed two times. In contrast, in the system with the task-based learning approach, the students had to continue trying to solve the task no matter how many times it took to get it right.

Figure 4. The spelling game involves using your finger to move the letters into the correct sequence to spell the target word

3.2. Participants

A total of 38 third graders whose average age was nine participated in this study. They were learning English as a Foreign Language (i.e., EFL) and studied English for three hours a week in an elementary school in northern Taiwan. It was the first semester of the English course, and the students were all beginners. A total of 20 students in one

class were assigned to be the experimental group, and 18 in the other class were the control group. The two classes were taught by the same instructor, a female teacher with more than ten years of elementary school teaching experience. All students had had previous experience of using a Tablet Personal Computer and were familiar with using their fingers to draw on a tablet.

3.3. Measuring Tools

The measuring tools adopted in this study were the pre-test, the post-test and the questionnaires of learning style, flow state, foreign language learning anxiety and cognitive load for measuring the students' performance. The pre-test aimed to assess whether the basic knowledge of the students of the two groups was equivalent before they participated in the learning activity. It consisted of seven matching items, with a perfect score of 100. The post-test at the end of all treatments employed seven multiple choice items for assessing their comprehension of the vocabulary, with a perfect score of 100. The assessment items were developed by two experienced English teachers, and corresponded to the learning content in the experiment.

The questionnaire of learning styles, the Index of Learning Styles (ILS) Questionnaire, was adopted for use in this study (Soloman & Felder, 2001). The ILS consists of four dimensions, each consisting of 11 items to distinguish the student's learning style from two contrary styles (Felder & Soloman, 1991). The four style dimensions and the contrary styles in each dimension are active/reflective, visual/verbal, sensing/intuitive and sequential/global (Felder & Silverman, 1988). The 'sequential/global' dimension was employed in this study to clarify whether the students with sequential learning preference or global learning preference learned better in each AR game system. The following are two example items from the 'sequential/global' dimension: "*I tend to (a)*

understand details of a subject but may be fuzzy about its overall structure; (b) understand the overall structure but may be fuzzy about details; *"* and "*It is more important to me that an instructor (a) lay out the material in clear sequential steps; (b) give me an overall picture and relate the material to other subjects*. Those items are related to the learning approaches designed in this study whereby the students using the self-directed AR educational game system were free to choose which challenge to confront first, while those in the task-based AR educational game were guided to experience each challenge task by task.

The questionnaire of flow states was modified from the measure developed by Kiili, de Freitas, Arnab, and Lainema (2012). It consisted of nine items with a five-point Likert rating scheme, such as "*The user interface of the learning system was easy to use. I could easily find all the necessary functionalities and information*" and "*I really enjoyed the playing experience. It was so gratifying that I want to capture it again for its own sake*." The Cronbach's alpha value of the questionnaire proposed by the original study was 0.78, implying acceptable reliability in internal consistency.

The cognitive load questionnaire was developed based on the measures of Paas (1992) and Sweller et al. (1998). It consists of 8 items with a six-point Likert rating scheme, including five items for "mental load" and three for "mental effort" (Hwang, Yang, & Wang, 2013). The Cronbach's alpha values of the two dimensions are 0.86 and 0.85, respectively.

The questionnaire of Foreign Language Classroom Anxiety Scale (FLCAS) was modified from the measure developed by Horwitz, Horwitz, and Cope (1986), and was translated into Chinese. The version used for the third grader students in this study only consisted of 8 items with a five-point Likert rating scheme with possible scores ranging from 8 to 40, such as "*I often feel like not going to my language class*" and "*I feel more tense and nervous in my language class than in my other classes.*" The Cronbach's alpha

value of the modified questionnaire was 0.78, while the Cronbach's alpha value of the original questionnaire was 0.93 (Aida, 1994), implying acceptable reliability in internal consistency.

3.4. Experimental Procedure and Data Analysis

There are two independent variables in the experimental design; one is the different learning approaches (i.e., the self-directed or task-based AR educational game) and the other is the different learning styles (i.e., the serial or global learning style) of the students. The dependent variables were the results of the post-test, flow state, foreign language learning anxiety and cognitive load. The experimental procedure is shown in Figure 5. After the pretest of English vocabulary and foreign language learning anxiety and the investigation of learning styles, the instructor explained the system operations by asking the students to use the AR system assigned according to her instructions and to apply the system to learn three target words which were not included in the following experiment.

Figure 5. Experimental Procedure

As for data collection and analysis, the statistical method of “two-way ANOVA” (Analysis of variance) was adopted to compare the flow state and cognitive loads of the different learning style students using the two systems. In addition, the statistical method of “two-way ANCOVA” (Analysis of covariance) was adopted for comparing the learning effectiveness and foreign language learning anxiety of the students with different learning styles in the two systems.

4. Experimental results

Students' learning styles have attracted much attention from researchers in recent

years. Accordingly, this study investigated the impact of the AR educational games using the two different learning approaches on the flow state, cognitive load and learning achievements of the students with different learning styles. The students were classified into serial and global learners based on their questionnaire ratings.

4.1. Flow states

A two-way ANOVA was conducted on the flow state of the students. There was no significant difference in Levene's Test of Equality of Error Variances ($F=0.63; p>.05$). Therefore, the null hypothesis that the error variance of the dependent variable is equal across groups was confirmed. The result of the two-way ANOVA is shown in Table 1. No significant impact was found on the interaction between learning approaches and learning styles ($F= 0.45, p > .05$), implying that directly investigating the main effects of independent variables on flow state is sensible. The significant effects were confirmed with learning approaches ($F=4.21^{*}, p < .05$) on the students' flow state. There were no significant effects of learning style ($F=0.66, p > .05$) on the students' flow state.

Table 1. Results of two-way ANOVA on students' flow state.

The flow state of the self-directed group (*Mean = 3.36; SD = 0.61*) was significantly higher than that of the task-based group (*Mean = 2.87; SD = 0.71*). Therefore, the students in the free environment felt that there was a better balance between the challenges and their proficiency levels. The results are shown in Table 2.

Table 2. The comparisons of the **flow state** of the students who learned with different learning approaches.

On the other hand, the flow state of the serial learning style students (*Mean = 3.02; SD= 0.79*) was not significantly lower than that of the global learning style students (*Mean = 3.22; SD = 0.55*), showing that the serial style students learned in a similarly enjoyable manner as the global style students.

4.2. Cognitive Load

In this study we were interested in the cognitive load of the students using the AR educational games. Cognitive load can be further divided into mental effort and mental load (Paas & Van Merriënboer, 1994). Mental effort is also named extraneous cognitive load and refers to the cognitive resources required to perform a task, implying that it is affected by the design of the learning approaches or the instructional design (Sweller et al., 1998). Therefore, it was expected that the two learning approaches in the current study could reduce extraneous cognitive load, making more working memory capacity available, and thus redirecting the students' attention to the cognitive processes directly relevant to the construction of their knowledge schemas.

A two-way ANOVA was conducted on the mental effort of the students. There was no significant difference in the Levene's Test of Equality of Error Variances ($F=1.97;\ p>.05$). Therefore, the null hypothesis that the error variance of the dependent variable is equal across groups was confirmed. The result of the two-way ANOVA is shown in Table 3. No significant impact was found on the interaction between learning approaches and learning styles ($F= 0.001,\ p > .05$), implying that directly investigating the main effects of independent variables on mental effort is sensible. There were no significant effects of the learning approaches ($F=0.156,\ p > .05$) on the students' mental effort. The significant effects were confirmed with

learning styles ($F=5.491^{*}$, $p < .05$) on the students' mental effort.

Table 3. Two-way ANOVA of students' extraneous cognitive load (mental effort)

The mental effort of the students in the self-directed group (*Mean = 1.83; SD = 1.07*) was as low as that of the students in the task-based group (*Mean = 1.92; SD = 0.78*), implying that the two groups both benefited in terms of their mental effort. In other words, using the two AR educational games to learn English did not cause the students heavy extraneous cognitive loading.

The mental effort of the students with different learning styles was also analyzed. The mental effort of the serial learning style students (*Mean = 1.59; SD= 0.81*) was significantly lower than that of the global learning style students (*Mean = 2.27; SD = 0.94*), showing that both of the games are more suitable for serial style students to use when learning English in a real-life situation. The results are shown in Table 4.

Table 4. Main effect of the mental effort on students with different learning styles

Mental load, also called intrinsic cognitive load, is mainly caused by the learning material. Because the learning content was vocabulary and the usage context was vocabulary for third grade students, it was expected that there would be no significant difference in the mental load of the students in the two groups. In addition to the learning material, mental load is also caused by the interaction among the task or subject characteristics. A two-way ANOVA was thus conducted on the mental load of the two groups of students. There was no significant difference in Levene's Test of Equality of Error Variances ($F=0.456; p>.05$). Therefore, the null hypothesis that the error variance of the dependent variable is equal across groups was confirmed. The

result of the two-way ANOVA is shown in Table 5. No significant impact was found on the interaction between learning approaches and learning styles (*F= 0.345, p > .05*), implying that directly investigating the main effects of independent variables on mental load is sensible. The students using different learning approaches had similar mental loads (*F=3.540, p > .05*). Moreover, the students with both serial and global learning styles also had similar mental loads (*F=0.615; p>.05*).

Table 5. The main effects of independent variables on the mental loads of the students

4.3. Foreign Language Learning Anxiety

A two-way ANCOVA was employed using the pre-test scores of foreign language learning anxiety as a covariate, learning approaches (task-based AR educational game/conventional self-directed educational game) and learning styles (serial/global) as independent variables, while the post-test scores of foreign language learning anxiety were a dependent variable. After verifying that the assumption of homogeneity of regression was not violated with *F = 1.175* (*p > .05*), the post-test scores of the four groups were analyzed with the two-way ANCOVA. As shown in Table 6, it was found that no significant effect was observed for the interaction between independent variables (*F = 1.193, p >.05*) on the students' foreign language learning anxiety, implying that directly investigating the main effects of independent variables on learning anxiety is sensible.

Table 6. Results of two-way ANCOVA of foreign language learning anxiety

No significant difference was found between the foreign language learning anxiety of the students who learned with the two different learning approaches (*F =*

3.162, p >.05). That is, the students using the two approaches performed similarly. The adjusted mean scores and the standard errors in the foreign language learning anxiety post-test of the students who learned with the task-based AR educational games are 19.94 and 2.32, compared with 14.44 and 2.05 for the students who learned with the self-directed game.

It was found that the foreign language learning anxiety (*Adjusted mean= 13.82, SE=1.98*) of the serial learning style students was much lower than that of the global learning style students (*Adjusted mean=20.56; SE=2.38*) ($F = 4.743^{*}$, *p <.05*), as shown in Table 7.

Table 7. Main effects of learning styles on foreign language learning anxiety

In Figure 6, the students with a serial learning style had the same low foreign language learning anxiety no matter whether they used the task-based or the self-directed learning approaches. However, the students with a global learning style had significantly higher foreign language learning anxiety when they used the task-based learning approach. In other words, providing tasks which restrict the learning choices of students with a global learning style caused them to have higher learning anxiety in comparison with those who had free choice during the AR assisted language learning.

Figure 6. The main effect of the learning styles on the anxiety of the students using different learning approaches

4.4. Learning effectiveness

A two-way ANCOVA was employed using the pre-test scores of learning

achievement as a covariate, learning approaches (task-based AR educational game/conventional self-directed educational game) and learning styles (serial/global) as independent variables, and the post-test scores of learning achievement as the dependent variable. After verifying that the assumption of homogeneity of regression was not violated with $F = 0.155$ ($p > .05$), the post-test scores of the four groups were analyzed with the two-way ANCOVA. As shown in Table 8, it was found that no significant effect was observed for the interaction between independent variables ($F = 0.664$, $p > .05$) on the students' learning achievements, implying that directly investigating the main effects of independent variables on learning effectiveness is sensible.

Table 8. Results of two-way ANCOVA on the learning achievement of the students

It was found that the learning effectiveness (*Adjusted mean= 82.20, SE=2.88*) of the serial learning style students was similar to that of the global learning style students (*Adjusted mean=75.46; SE=3.37*) ($F = 2.282$, $p > .05$), as shown in Table 9. Meanwhile, no significant difference was found between the learning achievements of the students who learned with the two learning approaches ($F = 0.235$, $p > .05$).

The students who used the two learning approaches all performed well. The adjusted mean score in the post-test of the students who learned with the task-based AR educational games was 79.91 compared with 77.75 for those who learned with the self-directed AR educational games. In sum, the two systems achieved high learning effectiveness for the students with both serial and global learning styles, so no significant difference was found between the two groups and the two learning styles.

Table 9. The descriptive data and the adjusted post-test scores

5. Discussion and Conclusions

Each student was equipped with a tablet PC in this study because previous research has confirmed that mobile learning results in better learning effectiveness for students (Al-Fahad, 2009), and especially the effective use of AR (Liu & Chu, 2010). The students had excellent learning effectiveness regardless of whether they used the self-directed or the task-based AR educational game system in this study. Many studies have also confirmed that students with different learning styles have different learning behaviors and requirements (Dunleavy & Dede, 2014). A previous study found that students with a global style are used to moving randomly, frequently and quickly around different organizations of materials, while students with a serial style are used to moving step by step, following a logical sequence (Soflano, Connolly, & Hainey, 2015). Therefore, two AR educational games based on self-directed and task-based learning approaches were developed and evaluated in this study.

It was concluded from the results of this study that the learning approaches (self-directed or task-based) played an important role in the flow experience of the students. The students who learned with the self-directed AR educational game experienced a higher flow state, implying that they could control the steps by themselves. Scholars have noted that the anxiety which students perceive would be greater than the flow they experience when the challenges they confront in the activities are beyond their ability and so are too difficult for them to complete; however, this did not happen in this study. In addition, too much learning anxiety may lead to worse performance and may further affect the students' intentions and motivations to continue learning (Csikszentmihalyi, 1975a, 1975b; Trevino & Webster, 1992; Webster et al., 1993). However, the flow experience of the students did not have a significant correlation with their learning anxiety and mental effort, no matter

whether they were playing the self-directed or the task-based AR game. In other words, the designs of the two systems took the proficiency level of the students into consideration, so as to provide an appropriate degree of challenge for EFL novices in elementary school.

It was found that the learning styles of the students played a critical role in their mental effort and the foreign language learning anxiety in this study. It was concluded that the students with a serial learning style had lower mental effort and foreign language learning anxiety. In particular, only for the serial learning style students who used the self-directed AR educational game was there a significantly positive correlation between their foreign language learning anxiety and their learning improvement ($Pearson = 0.637^{*}$, $p<0.05$). In other words, for foreign language learning performance, it is not a case of the less anxiety the better (Park & French, 2013).

In addition, the relation between learning anxiety and mental effort revealed a high positive correlation for the students using the self-directed game ($Pearson = 0.842^{**}$, $p<0.01$), but a low positive correlation for the task-based game ($Pearson = 0.461^{**}$, $p<0.05$). Overall, the mental efforts of the students were greater when they had more learning anxiety at the same time. It is therefore inferred that appropriate but not excessive mental effort and foreign language learning anxiety are necessary for achieving learning effectiveness. Furthermore, it is suggested that students with a global learning style should not use task-based AR educational games for learning English because the higher learning anxiety and mental effort they experience do not result in better learning effectiveness. On the contrary, cognitive load that is too high would result in lower learning performance (Skulmowski, Pradel, Kühnert, Brunnett, & Rey, 2016). The students with a global learning style did not like to restrict their learning steps as was required in the task-based AR educational game (Tortorella &

Graf, 2015). For system design, it is suggested that it is not necessary to provide tasks which restrict which station students should start at when the sequence among the actual situational stations does not have a rigorous logical linear relation. Freedom is one of the features of most AR learning systems, and the side effects of AR, such as mental effort or learning anxiety, could be reduced when the design is adapted to the students' degree of challenge and control.

The sample size was small in this study because the classroom with the situated setting could not accommodate too many students at one time. In addition, because the students were only third graders, the learning targets were all objects. The results may therefore be unsuitable for generalization to older students. This intervention was not long, but it was longer than another recent study (Skulmowski, Pradel, Kühnert, Brunnett, & Rey, 2016) in which participants only spent approximately 20 minutes using either version of the system. Therefore, future studies could extend this method to include more learning targets in real life and make the intervention period longer. More human factors such as gender, spatial ability and so on can be employed for analysis in the future. In addition, future studies could take self-efficacy into consideration. That is, it can be identified whether students feel that they learn better using an AR system in a real-life setting.

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Captions of Figures

Table 1. Table 1. Results of two-way ANOVA on students' flow state.

Source	SS	df	MS	*F*	Partial eta²
Learning approaches	154.54	1	154.54	*4.21**	0.110
Learning Styles	24.13	1	24.13	*0.66*	0.019
Learning approaches × Learning styles	16.62	1	16.62	*0.45*	0.013

**p<.05*

Table 2. Comparison of the **flow state** of the students who learned with different learning approaches.

Learning approaches	N	Mean	SD	Adjust Mean	SE	*F*
Self-directed	18	3.36	0.61	3.36	0.16	*4.21**
Task-based	20	2.87	0.71	2.91	0.15	

**p<.05*

Table 3. Two-way ANOVA of students' extraneous cognitive load (mental effort)

Source	SS	df	MS	*F*	Partial eta²
Learning approaches	0.123	1	0.123	*0.156*	0.005
Learning Styles	4.328	1	4.328	*5.491**	0.139
Learning approaches □×Learning styles	0.001	1	0.001	*0.001*	0.000

**p<.05*

Table 4. Main effect of the mental effort on students with different learning styles

Learning Styles	N	Mean	SD	Adjust Mean	SE	*F*
Serial	22	1.59	0.81	1.59	0.19	*5.491**
Global	16	2.27	0.94	2.27	0.22	

**p<.05*

Table 5. The main effects of independent variables on the mental loads of the students

Independent variance	Groups	N	Mean	SD	Adjust Mean	SE	*F*
Learning approaches	Self-directed	18	1.57	1.04	1.57	0.22	*3.540*
	Task-based	20	2.10	0.77	2.14	0.21	
Learning Styles	Serial	22	1.75	0.89	1.74	0.20	*0.615*
	Global	16	1.98	1.02	1.98	0.23	

Table 6. Results of two-way ANCOVA of foreign language learning anxiety

Resources	SS	df	MS	*F*	Partial eta²
Covariance	102.788	1	102.788	*2.200*	0.068
Learning approaches	147.721	1	147.721	*3.162*	0.095
Learning styles	221.583	1	221.583	*4.743**	0.137
Learning approaches × Learning styles	55.74	1	55.74	*1.193*	0.038

**p<.05*

Table 7. Main effects of learning styles on foreign language learning anxiety

Learning Styles	N	Mean	SD	Adjusted mean	SE	*F*
Serial	22	13.14	6.07	13.82	1.98	*4.743**
Global	16	15.38	8.66	20.56	2.38	

**p<.05*

Table 8. Results of two-way ANCOVA on the learning achievement of the students

Source	SS	df	MS	*F*	Partial eta²
Covariance	14146.405	1	14146.405	*75.740****	0.716
Learning approaches	124.488	1	124.488	*0.667*	0.022
Learning Styles	519.897	1	519.897	*2.784*	0.085
Learning approaches × Learning styles	201.809	1	201.809	*1.080*	0.035

****p<.001*

Table 9. The descriptive data and the adjusted post-test scores

Learning approaches	Learning styles	N	Mean	SD	Adjusted Mean	SE
Self-directed	Serial	10	82.86	25.91	82.91[a]	4.32
	Global	8	78.57	22.91	70.13[a]	5.25
Task-based	Serial	12	77.38	23.95	81.20[a]	4.04
	Global	8	78.57	27.53	78.33[a]	4.83

a. Pre-test is the covariant

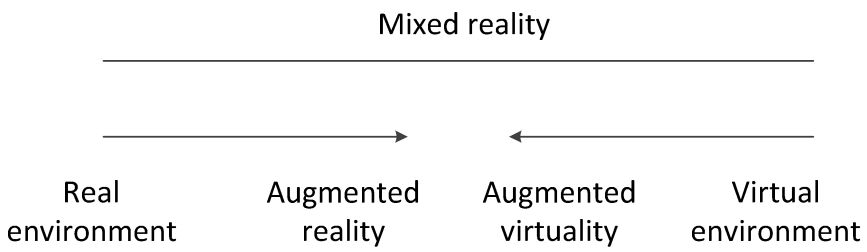

Figure 1. Milgram's Reality-Virtually Continuum (Milgram & Kishino, 1994)

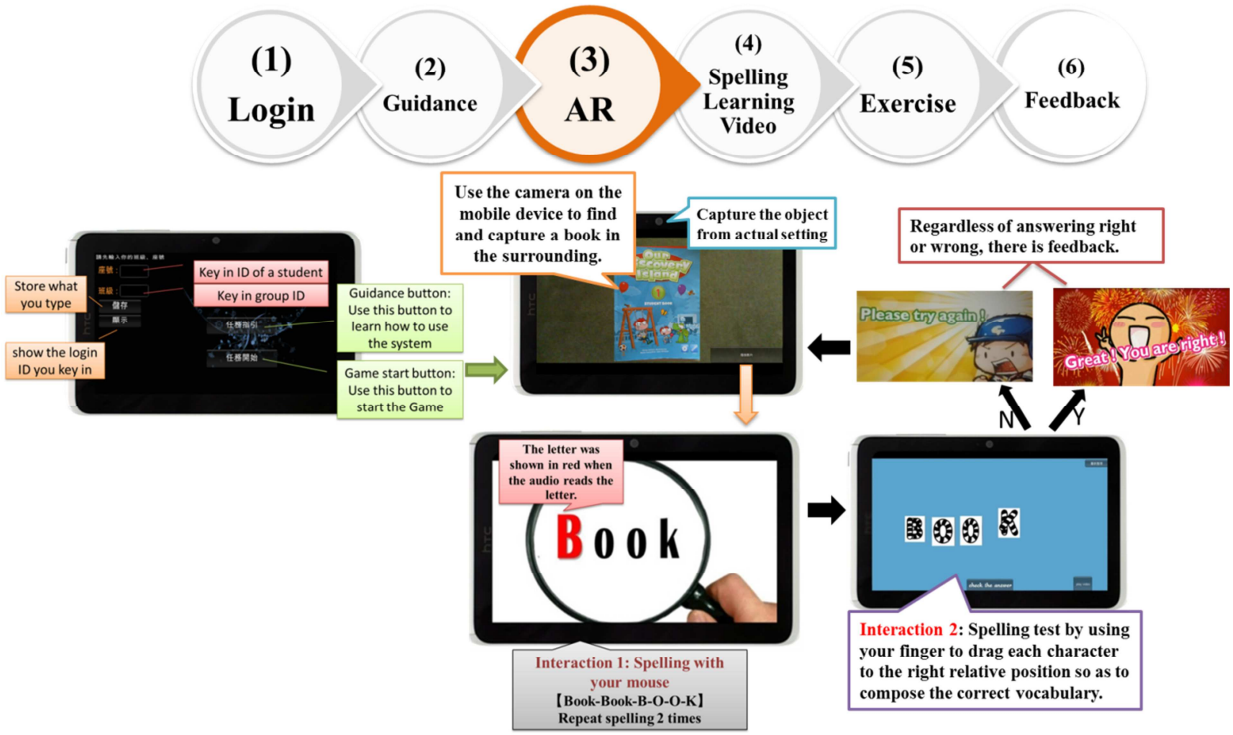

Figure 2. Six screenshots illustrating the vocabulary AR game

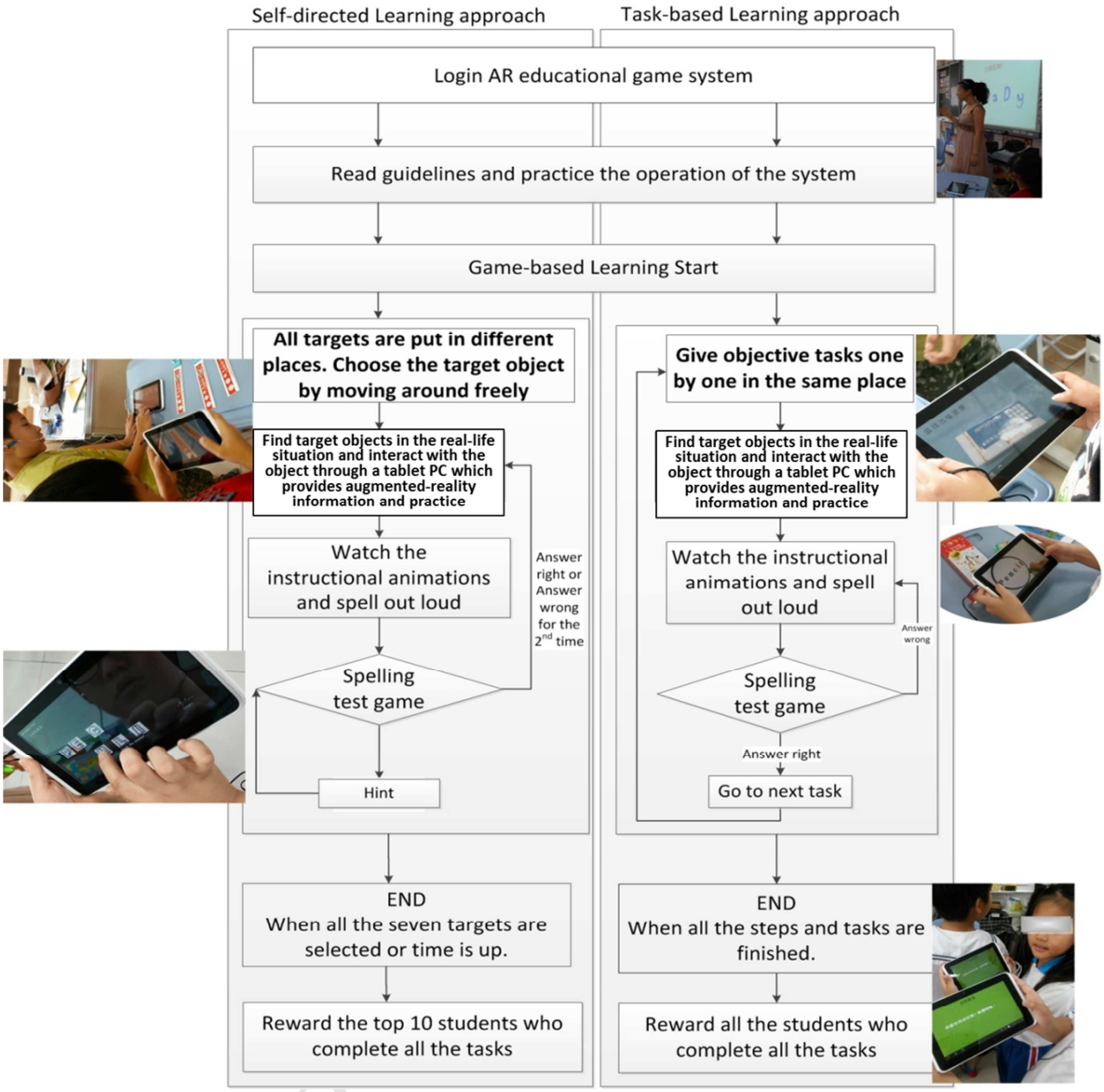

Figure 3. System Framework of Self-directed and Task-based AR educational game

Figure 4. The spelling game involves using your finger to move the letters into the correct sequence to spell the target word

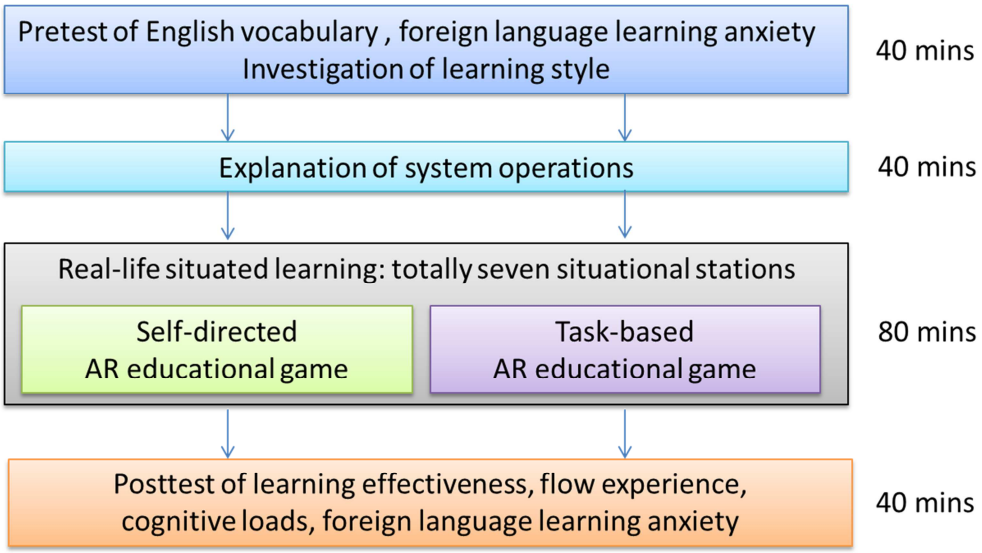

Figure 5. Experimental Procedure

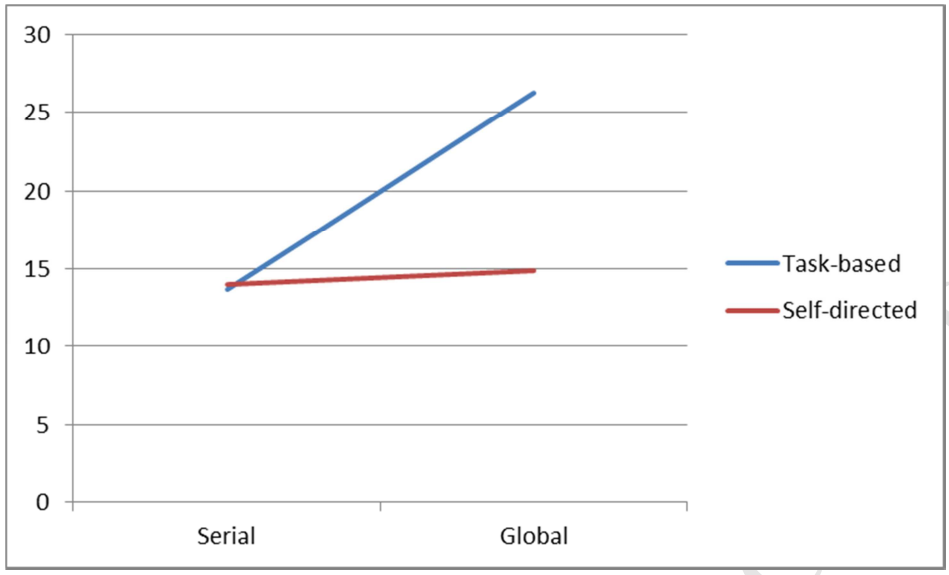

Figure 6. The main effect of the learning styles on the anxiety of the students using different learning approaches

Highlights

- Two AR educational games were developed for third graders to learn English.
- One game used a self-directed learning approach not limiting the learning sequence.
- The other one used a task-based learning approach assigning learning sequence.
- The students using the self-directed system revealed higher flow experience.
- The students with a serial learning style had lower mental effort and anxiety.