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Using an Instructional Book with Augmented Reality Technology based on Brain-Based Learning to Foster Learning Outcomes of Undergraduate Students in Sukhothai Thammathirat Open University

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Abstract

This research aims to evaluate the effectiveness of using an instructional book with augmented reality technology based on brain-based learning for undergraduate students of Sukhothai Thammathirat Open University. The evaluation was based on two factors: (1) pre- and post-experimental learning achievement scores, which were compared using the relative gain scores formula, and (2) student satisfaction after learning with the instructional book with augmented reality technology based on brain-based learning. This research used a quasi-experimental design. The target group was 24 undergraduate students in the School of Agriculture and Cooperatives, registered for online supplementary teaching, Course 90201 Farm Management, in the first semester of 2022. They were selected using the purposive sampling method. The research instruments were (1) the instructional book with augmented reality technology based on brain-based learning, (2) the learning achievement test, and (3) the satisfaction assessment. The data were analyzed using a relative gain score, mean, standard deviation, and percentage. The research found that the results of using the instructional book with augmented reality technology based on brain-based learning showed that most students' relative gain score was high (between 52.63% and 73.68%), and the student's overall satisfaction was at a high level ($\bar{x}$ = 4.22, S.D. = 0.79).

Keywords: augmented reality technology, brain-based learning, instructional book, multiple senses, open university, progressive learning, real experience, undergraduate student.

1. Introduction

Sukhothai Thammathirat Open University is an open university that utilises distance learning systems. It offers collaborative learning activities using various multimedia. For undergraduate education, printed materials are primarily used alongside digital media such as video clips or audio clips as supplementary materials. Additionally, various interactive activities are employed to help students achieve the learning outcomes of the courses. Students engage in self-directed learning at their own pace and convenience.

Based on the evaluation of the teaching and learning management of Course 90201: Farm Management, under the School of Agriculture and Cooperatives, Sukhothai Thammathirat Open University, for the academic years 2/2012-2/2017, it was found that the majority of students were satisfied with the content

of the instructional materials, which could be applied practically in their work. However, as the primary media is an instructional book printed in monochrome, there were suggestions regarding using colour images to make the content easier to understand, increase the interest in the instructional materials, and reduce the monotony of reading plain text alone. Additionally, some parts of the content were extensive and challenging, requiring students to study or read repeatedly to comprehend the material.

Digital technology has a significant influence on both the global economy and society as a whole. In education, digital technology plays a crucial role in enhancing the efficiency of teaching and transforming the learning processes of students. As stated by NaSongkhla (2018), the potential of digital technology has an impact on teaching and learning. This technology extends the classroom to real-life learning contexts through communication channels, computer networks, and the online world. Pedagogical approaches and teaching methods have shifted towards processes where learners are actively engaged in self-directed learning.

Digital technology such as Augmented Reality (AR) is one of the Extended Realities (XR) technologies, which create limitless virtual worlds. AR allows real-world environments and virtual objects to coexist in the same image. According to Arena et al. (2022), AR is aimed at merging and extending users' physical environment or digital real-time world by adding layers of digital data. This integration can be applied to various display technologies that can overlay or combine data such as numbers, letters, symbols, sounds, videos, and graphics, with the user's perspective in the real world. Therefore, AR can be applied in diverse ways. In educational institutions, AR technology can be used to develop responsive teaching materials, especially printed media. Utilising AR technology in educational print media helps transcend the limitations of traditional printed materials, which are perceived solely through visual senses, to materials that engage both visual and auditory senses. This new era of learning can present various static images beyond those found in books, such as short videos, allowing learners to study examples from different perspectives, and thus enhancing their understanding of the content (Nakasan & Ruangvanich, 2016).

Brain-Based Learning (BBL) is an educational approach that emphasises learning processes originating from the brain. It integrates principles from neuroscience and cognitive science into teaching and learning activities. The key principle is that learning should begin by creating an environment conducive to brain-based learning. This involves a friendly learning atmosphere that challenges learners without overwhelming them. Information linked to emotions and feelings helps our brains retain it better. In terms of content presentation, lessons should stimulate brain perception, starting from simple concepts and progressing to more complex ones. Learning activities should be diverse, stimulating brain usage through visual, auditory, and tactile stimuli, as well as through various events or hands-on experiences. This enhances the interconnectedness of memory circuits and the perception of different information. Regarding practical training, frequent hands-on experiences reinforce existing brain cells and increase stability, leading to better memory retention (Caine, 1994; Office of Knowledge Management and Development, 2015; Wiangwalai, 2013).

Based on the importance and advancement of technology and educational management science, the integration of augmented reality (AR) technology and brain-based learning concepts into undergraduate instructional book at Sukhothai Thammathirat Open University has led to the design and development of instructional materials. These materials aim to enable students to learn independently through brain-based learning principles and processes, utilising AR technology in learning activities at various stages. By scanning AR codes or markers in an instructional book, students can access augmented reality images and video clips that serve as supplementary materials, enhancing their understanding beyond lecture summaries. Moreover, these materials link students to external learning resources relevant to the content of the instructional unit, facilitating self-assessment activities before and after learning, as well as experiential learning activities within each lesson segment. This integrated approach encompasses core and supplementary media, along with teaching and learning activities at the university. It enables students to learn effectively through the use of augmented reality technology.

Researchers have studied the effectiveness, outcomes, and satisfaction of students in learning through such augmented reality-enhanced instructional books to provide insights into their learning performance

and satisfaction levels (Maneenil et al., 2023). It can be seen that the aforementioned framework encompasses core media, supplementary media, and teaching and learning activities at Sukhothai Thammathirat Open University. This integration enables students to learn effectively through the use of augmented reality technology. The researchers have studied the outcomes, effectiveness, and satisfaction of students in learning through such an augmented reality-enhanced instructional book to provide insights into their learning performance and satisfaction levels.

1.1. Research objectives

i. Compare learning achievement scores before and after learning with the instructional book with augmented reality technology based on brain-based learning.

ii. Investigate the satisfaction levels of undergraduate students at Sukhothai Thammathirat Open University after learning with the instructional book with augmented reality technology based on brain-based learning.

2. Literature Review

2.1. Augmented Reality Technology

Augmented reality technology is the use of the virtual world to expand or supplement the real world or the integration of reality and virtuality with digital technology. This is delivered in the form of layers or overlays of data, images, and animation through digital devices with application programs installed to display this augmented reality in the real world. The main components of augmented reality technology consist of four parts: 1) A maker is a mark, symbol, or image specified for comparison with what is stored in the database (Marker Database). 2) A camera is a camera on a mobile device that can detect various sensors to analyse the image. 3) AR software is software or processing to display it as an image, and (4) A monitor is a display screen, mobile phone screen, or other device used to display images, superimposed data, symbols, or pictures, which are displayed from a marker. Arena et al., 2022; Nakasan & Ruangvanich, 2016; Pakorn, 2018).

Currently, AR technology has been applied in education, particularly in displaying the results of AR technology for teaching and learning activities. This is delivered in three main ways: 1) Displaying 2D or 3D image data so that learners can see realistic colour illustrations or places and objects that cannot be displayed in the classroom, 2) Displaying teaching video clips so that learners can study from teaching video clips, helping learners to receive information through both the eyes and ears, which is not limited to reading with the eyes alone, and 3) Displaying interactive activities so that learners can do various interactive activities, promoting the process of participation in learning by interacting with the lesson and learners receiving immediate feedback, including links to other applications to allow learners to learn together, expanding the learning outcomes of learners more widely (Loesanakkhaphan, 2018; Nakasan & Ruangvanich, 2016).

2.2. Brain-Based Learning

Brain-based learning is learning management by applying knowledge of neuroscience and learning to design instruction to be consistent with the natural functioning of the brain, that is, both the left and right hemispheres of the brain work together, using a variety of appropriate processes and methods. There are four important principles of brain-based learning: 1) preparation of the body, mind, and environment; 2) learning from the senses; 3) a challenging but stressful learning environment; 4) learning from easy to difficult; and 5) learning through real experience (Jensen, 2008; Office of Knowledge Management and Development, 2015; Wiangwalai, 2013). In addition, in practice, there are four steps of brain-based learning as follows: Step 1: Prepare the brain, Step 2: Learn through multiple senses, Step 3: Practice and give feedback, and Step 4: Expand knowledge.

2.3. Utilising Augmented Reality Technology in Each Stage of Brain-Based Learning

This section elucidates the steps in utilising AR technology within a brain-based learning approach.

Stage 1: Prepare the brain activities
Learners scan AR markers to engage in activities related to the content they are about to study, preparing them for unit-level content. Activities such as matching related terms from the unit content create a challenging and enjoyable learning environment. This stage prepares learners' brains to connect with the forthcoming material.

Stage 2: Learn through multiple senses activities
Learners scan AR markers to study unit-specific content through various media formats, engaging multiple senses such as reading, viewing, and listening. The content is organised from simple to complex and from general to detailed, facilitating comprehension through a structured progression.

Stage 3: Practice and Feedback activities
Learners scan AR markers to complete post-study exercises that emphasise a challenging and experiential learning atmosphere. These exercises allow learners to repeatedly test their knowledge from the previous stages. The exercises can be attempted an unlimited number of times, with immediate feedback provided by the program to support the learning process.

Stage 4: Expand knowledge activities
Learners scan AR markers to participate in discussions using the Padlet application. This stage connects and applies learned knowledge to new situations, encouraging learners to exchange ideas with classmates on discussion topics posed by the instructor. This promotes collaborative learning and deeper understanding of the material.

3. Research Methodology

3.1. Population, Sample, and Sampling

The population is students at the Department of Agriculture and Cooperatives, Sukhothai Thammathirat Open University, specialising in Agricultural Management with a concentration in Agricultural Business, who registered for the course 90201 Farm Management in the first semester of the academic year 2022. The experimental group comprised 24 undergraduate students, who were selected using the purposive selection criteria as follows.

i. The students who have registered for and were enrolled in the online supplementary teaching course, Course 90201: Farm Management, in the first semester of the academic year 2022.
ii. The students need to have digital devices or smartphones that can install applications and display augmented reality (AR) technology.

3.2. Research Instrument

The instructional book with augmented reality technology based on brain-based learning for undergraduate students at Sukhothai Thammathirat Open University was designed and developed. AR Maker was incorporated in the form of images and arranged in the instructional book. The learning process follows the principles of brain-based learning. When scanned by the students, the results will be displayed in the following formats: (1) displaying 2D image data, such as mind map presentations, and image galleries; (brain-based learning step 1: prepare the brain); (2) displaying video clip data, such as short summary lecture videos for each section of the content (brain-based learning step 2: learn through multiple senses); and (3) displaying interactive activities, such as pre-learning readiness activities, post-learning activities, providing feedback information (brain-based learning step 3: practice and give feedback); and linking to the Padlet application for collaborative discussions with other students (brain-based learning step 4: expand knowledge) The quality of the instructional book with augmented reality

technology based on brain-based learning was assessed by six experts in educational technology and content, and rated highly ($\bar{x}$ = 4.49, S.D. = 0.58).

The learning achievement test is a multiple-choice test with five options, consisting of thirty (30) questions that have been evaluated by three experts in measurement, assessment and content. The Item-Objective Congruence (IOC) index ranged from 0.67 to 1.00, indicating the degree of alignment between the dimensions or components of the test and the objectives to be evaluated. Then, the test was tested with a sample group of thirty (30) students from the School of Agriculture and Cooperatives, Sukhothai Thammathirat Open University, who had previously taken the course 90201 Farm Management, to measure the difficulty index (p), the discrimination index (r), and the reliability of the test (rtt). The difficulty index (p) ranged from 0.23 to 0.80, the discrimination index (r) ranged from 0.20 to 0.60, and the overall reliability of the test (KR-21) was 0.86.

The student satisfaction assessment was conducted using a five-point Likert scale, with evaluation items divided into the following four dimensions: (1) instructional book dimension, (2) self-directed learning with augmented reality technology dimension, (3) self-directed learning activities from instructional book with augmented reality technology based on brain-based learning, and (4) benefits derived from learning with instructional book with augmented reality technology based on brain-based learning. In total, twenty (20) item questions were evaluated by three experts in educational technology and content. The Item-Objective Congruence (IOC) index ranged from 0.67 to 1.00.

3.3. Collection of Data

This research is a quasi-experimental study using the One Group Pretest-Posttest Design (Campbell & Stanley, 1963), as shown in Table 1.

Table 1. One Group Pretest-Posttest Design

Pre-test	Treatment	Post-test
O1	X	O2

Note. O1: Before study
O2: After study
X: Learning with an instructional book with augmented reality technology based on brain-based learning

The quasi-experiment was conducted, and data was collected as follows:

The researchers collected data during the first semester of 2022, from September 15, 2022, to January 18, 2023, in the course 90201: Farm Management. The researchers scheduled online teaching for 24 participants who were enrolled in the course and had signed up for online teaching. The online teaching programme was offered by the university and was voluntary. Data were collected from two online teaching sessions: the first in December 2022 and the second in January 2023. The instructional book with augmented reality technology based on brain-based learning was delivered to the students.

The researcher outlined the research process and instructed the experimental group to proceed according to the following procedures:

i. The experimental group completed a pre-learning achievement test.
ii. The experimental group studied and engaged in activities using the instructional book with augmented reality technology based on brain-based learning.
iii. The experimental group completed a post-learning achievement test.
iv. The experimental group completed a post-learning satisfaction assessment using an instructional book with augmented reality technology based on brain-based learning.

3.4. Data Analysis

The learning achievement scores before and after the experiment were analysed by comparing the learning progress scores using the relative gain score (Kanjanawasee, 2014). The analysis was done using Microsoft Excel.

The criteria for interpreting the meaning of the relative gain score are as follows (Kanjanawasee, 2014):
0 – 24.99 - Initial level development
25.00 – 49.99 - Intermediate level development
50.00 – 74.99 - High level development
75.00 – 100.00 - Very high level development

The data from the post-learning satisfaction assessment were analysed by calculating the mean and standard deviation of the assessment scores.

The criteria for interpreting the meaning of average satisfaction scores are as follows (Leekitchwatana, 2015):
Average score of 5.00 – 4.51 - Very satisfied
Average score of 4.50 – 3.51 - Satisfied
Average score of 3.50 – 2.51 - Moderately satisfied
Average score of 2.50 – 1.51 - Dissatisfied
Average score of 1.50 – 1.00 - Very dissatisfied

4. Findings and Discussion

4.1. Findings

The results of using augmented reality technology to supplement an instructional book according to the principles of brain-based learning among undergraduate students at Sukhothai Thammathirat Open University can be summarised as follows.

4.1.1. Pre-experimental and post-experimental learning achievement scores

Pre-experimental and post-experimental learning achievement scores, comparing learning development scores using the relative gain score formula, yielded the results as shown in Figure 1.

The analysis of the relative gain score between learning achievement scores before and after learning reveals that among the experimental group comprising 24 students, the majority of students showed high-level development, with 13 students (equivalent to 54.17 percent). Their relative gain score ranged between 52.63% and 73.68%. The next tier consisted of students showing intermediate development, totalling 10 individuals (equivalent to 41.67 percent). Their relative gain score ranged between 35.29% and 47.83%. Additionally, there was one student exhibiting very high-level development, with a relative gain score of 80.95%.

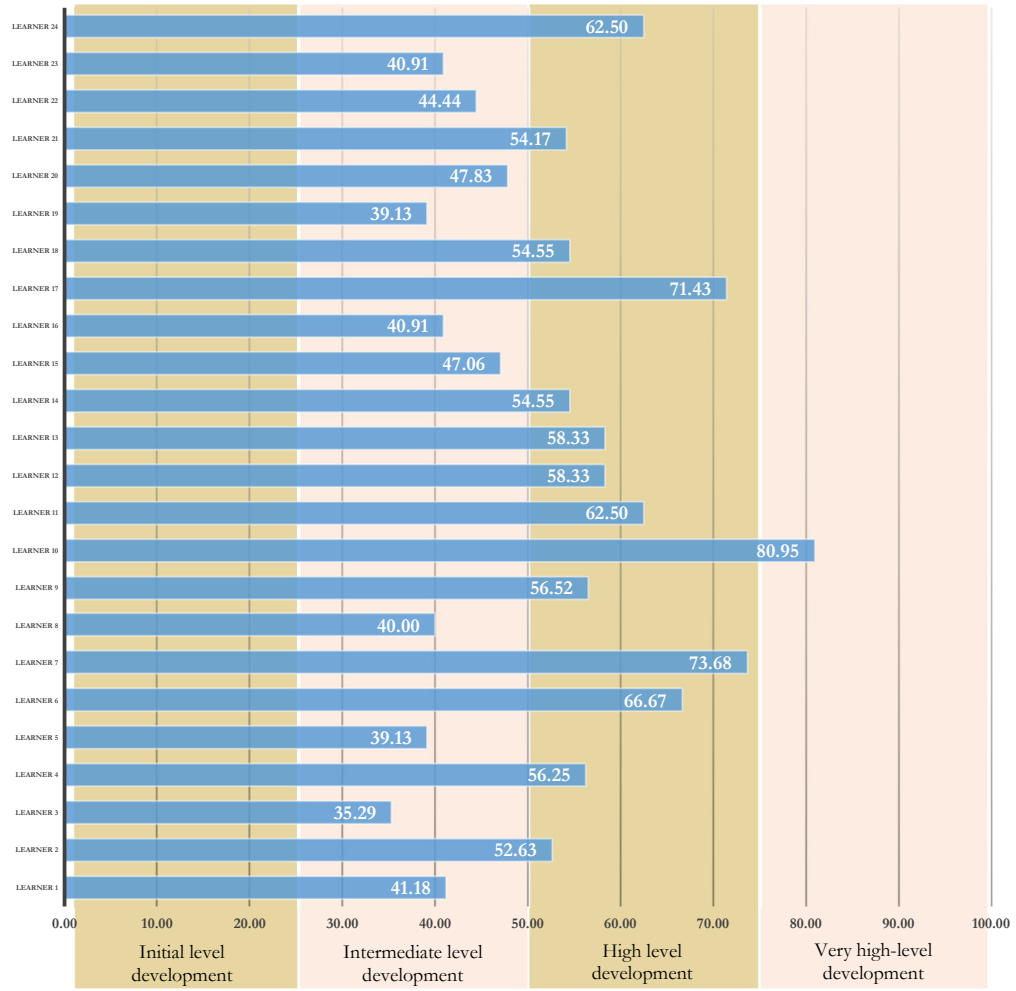

Figure 1. The results of the analysis of relative gain score formula between learning achievement scores before and after learning.

4.1.2. Overall average scores before and after learning

Comparison of the overall average scores before and after learning with the instructional book with augmented reality technology based on brain-based learning shows that the students' relative gain score increased at a high level, as shown in Table 2.

Table 2. Summary of pre- and post-test scores of students after learning with the instructional book with augmented reality technology based on brain-based learning (n=24)

	Pre-test scores	Post-test scores	Relative gain score	Development level
Full score	720	720		
Actual score	245	497		
Average score	10.21	20.71	53.05	High level

As shown in Table 2, the average score before learning was 10.21 points, and after learning with the instruction book with augmented reality technology based on brain-based learning, the average score after learning was 20.71 points with a relative gain score of 53.05. The results indicate that the learners have developed at a high level overall.

4.1.3. Assessment of student satisfaction

The results of the assessment of student satisfaction after learning with an instructional book with augmented reality technology based on brain-based learning are shown in Table 3.

Table 3. The results of the evaluation of student satisfaction after learning with instructional book with augmented reality technology based on brain-based learning (n=24)

Questions	Mean	S.D.	Satisfaction Level
Instructional book aspect	**4.51‡**	**0.63**	**Very satisfied**
1. The format of the reading book facilitates easy understanding.	4.46	0.66	Satisfied
2. The font used is easy to read.	4.58	0.66	Very satisfied
3. Graphical images are sharp and clear in print.	4.50	0.59	Satisfied#
Self-learning media with augmented reality (AR) technology aspect	**4.04**	**0.80**	**Satisfied**
1. Convenience in downloading the AR application for use.	3.88	0.68	Satisfied
2. The size of the AR code (symbols or signs) used for scanning is appropriate, sharp, and easy to scan.	3.88	0.68	Satisfied
3. Quick access to information from scanning and various links.	4.00	0.72	Satisfied
4. Images, graphics, and text in the learning book are clear and easily understandable.	4.13	0.80	Satisfied
5. Narration in video clips is clear and audible, not too loud or too soft.	4.00	0.88	Satisfied
6. The presentation format of the media is appropriate and interesting.	4.21	0.83	Satisfied
7. The duration of each video clip presentation is suitable.	3.88	0.85	Satisfied
8. Instructions and commands in the learning book are clear and easy to understand.	4.21	0.88	Satisfied
9. Ease of use of the AR application.	4.17	0.87	Satisfied
Self-learning activities from instructional book with augmented reality technology based on brain-based learning aspect	**4.33**	**0.78**	**Satisfied**
1. Pre-content questioning or discussion activities help prepare students before engaging with the content of each unit.	4.29	0.75	Satisfied
2. Presenting learning book with augmented reality technology offers a variety of options, such as scanning AR codes to view summarized concept maps and colourful illustrations, conducting pre- and post-learning achievement, and accessing video media with content summaries. This diversity facilitates easier comprehension of the content in each chapter.	4.25	0.79	Satisfied
3. Engaging in self-assessment activities before and after learning, receiving immediate feedback, enables better self-assessment of knowledge and understanding, enhancing one's learning experience.	4.42	0.78	Satisfied
4. Linking to relevant learning resources helps expand understanding of the studied content even further.	4.38	0.82	Satisfied
The benefits gained from learning with instructional book with augmented reality technology based on brain-based learning aspect	**4.31**	**0.79**	**Satisfied**
1. This learning media makes learners feel engaged and enjoy the learning process.	4.21	0.72	Satisfied
2. This learning media enables learners to engage in self- learning more effectively.	4.46	0.72	Satisfied
3. This learning media is contemporary and can significantly enhance learner engagement.	4.38	0.77	Satisfied
4. This learning media helps learners better understand the study content.	4.21	0.93	Satisfied
All aspect	**4.22**	**0.79**	**Satisfied**

From Table 3, it can be concluded that the overall satisfaction rating of students after learning with instructional book with an augmented reality technology based on brain-based learning was "satisfied" ($\bar{x}$ = 4.22, S.D. = 0.79).

Regarding the instructional book aspect, students responded that they were very satisfied ($\bar{x}$ = 4.51, S.D. = 0.63). Specifically, the aspect with the highest evaluation score is the readability of the font used ($\bar{x}$ = 4.58, S.D. = 0.66), which was rated at the "very satisfied" level.

The students rated the self-learning activities at the "satisfied" level ($\bar{x}$ = 4.33, S.D. = 0.78). Specifically, the aspect with the highest evaluation score is the self-assessment activities before and after learning, with immediate feedback, enabling better self-assessment of knowledge and understanding ($\bar{x}$ = 4.42, S.D. = 0.78), which were rated as "satisfied". Next, the students also rated the aspect of linking to relevant learning resources, which helps expand understanding of the studied content even further ($\bar{x}$ = 4.38, S.D. = 0.82) as "satisfied".

The benefits derived from learning with an instructional book with augmented reality technology based on brain-based learning received "satisfied" rating ($\bar{x}$ = 4.31, S.D. = 0.79). Specifically, the aspect with the highest evaluation score was that this learning media enables learners to engage in self- learning more effectively ($\bar{x}$ = 4.46, S.D. = 0.72), which also received a "satisfied" rating. Similarly,, the item stating that this learning media is contemporary and significantly enhances learner engagement ($\bar{x}$= 4.38, S.D. = 0.77), was also rated as "satisfied" by the students.

Regarding a self-learning book with augmented reality (AR) technology, this was also rated at the "satisfied" level ($\bar{x}$ = 4.04, S.D. = 0.80). Specifically, the aspect with the highest evaluation score is the appropriateness and interest of the media presentation format, as well as the clarity and ease of understanding of instructions and commands in the learning materials ($\bar{x}$ = 4.21, S.D. = 0.88), which were all rated at the "satisfied" level. Next is the ease of use of the AR application ($\bar{x}$ = 4.17, S.D. = 0.87), also rated at the "satisfied" level.

4.2. Discussion

The results of using the Instructional Book with Augmented Reality Technology based on Brain-Based Learning Principles

The results of utilising teaching materials designed with augmented reality (AR) technology in alignment with brain-based learning principles revealed significant improvements in learning outcomes. A comparison of pre-learning and post-learning scores indicated an increase in academic achievement among all learners, with the majority demonstrating a high level of development (13 students, or 54.17%). This improvement can be attributed to the integration of AR technology and brain-based learning principles in the design and development of the teaching materials.

The instructional process incorporated both principles and stages of brain-based learning, creating activities that aligned with the learners' brain functions. The process began with the **prepare the brain stage**, where learners engaged in AR-based activities, such as matching terms related to the upcoming content, to stimulate readiness before delving into the subject matter. Next, in the **learn through multiple senses stage**, learners used AR markers to explore content through various media formats, including text, images, and video clips. This stage involved sensory engagement through reading, viewing, and listening, with content organised progressively from simple to complex and general to detailed. In the **practice and give feedback stage**, learners used AR markers to complete exercises, reinforcing their understanding through repetition and immediate feedback. This stage enhanced fluency and accuracy in applying the acquired knowledge. The process concluded with the **expand knowledge stage**, where learners scanned AR markers to access activities on applications such as Padlet. These activities facilitated knowledge application and discussion, enabling learners to connect and expand upon what they had learned while engaging with peers in interactive discussions.

This instructional approach aligns with the stages of brain-based learning described by Jensen (2008), which include:

1. **Preparation** – Stimulating the brain to receive new information.
2. **Acquisition** – Learning and absorbing the content.
3. **Elaboration** – Adding detailed knowledge.
4. **Memory Formation** – Creating lasting memories of the learned material.
5. **Functional Integration** – Applying knowledge in practical contexts.

The use of AR technology in this process enhanced learning engagement, reduced the limitations of traditional printed materials, and facilitated interactive activities through learners' smartphones. This finding aligns with the research by Loesanakkhaphan (2018), which highlighted that AR technology increases student interest and engagement by embedding AR elements in modern teaching materials.

Research by Chaimongkhol et al. (2020) demonstrated that two-dimensional AR technology in teaching materials significantly improved students' academic performance. Similarly, this study reflects the potential of AR technology to overcome the limitations of conventional teaching documents, as learners can interact with digital overlays in real-world environments, creating a more flexible, engaging, and personalised learning experience.

According to Dynamics 365 (2023), AR technology enhances teaching and learning by adding digital components to real-world perspectives. The incorporation of AR facilitates immersive environments, enabling interactions with digital visuals, sounds, and stimuli that complement physical reality. Additionally, Yildiz (2021) emphasised that AR in education provides learners with flexible, engaging environments that bridge formal and informal learning, offering opportunities for collaborative learning and innovation.

Results of Learner Satisfaction Evaluation

The overall learner satisfaction with the teaching materials using augmented reality (AR) technology based on brain-based learning principles was rated at a high level ($\bar{x}$ = 4.22, S.D. = 0.79). These teaching materials effectively captured learners' attention, stimulated motivation, and fostered engagement through interactive elements such as graphic visuals, animations, and learning activities. This finding aligns with the study by Min-Chai Hsieh and Fan-Ray Kuo (2014), which investigated the impact of AR technology on learners' performance in studying English prepositions. Their AR-integrated approach, featuring text, audio, graphics, animations, and interactive content, created an innovative and engaging learning environment. Learners reported that the AR-based materials were easy to use, beneficial, and significantly enhanced their learning experience. The highest satisfaction score for teaching materials in their study was also at a very high level ($\bar{x}$ = 4.51, S.D. = 0.63), with the most highly rated aspect being the use of easy-to-read fonts ($\bar{x}$ = 4.58, S.D. = 0.66).

In addition to aligning learning activities with brain-based learning principles, the teaching materials were designed based on research by Buasri (2016). This study focused on developing undergraduate teaching document layouts at Sukhothai Thammathirat Open University. The findings recommended the use of the Thai Sarabun font in size 16 points for its clarity and readability. The document layout also employed single-column formats on both front and back pages to facilitate ease of reading.

The self-paced learning activities using AR technology were rated highly satisfactory ($\bar{x}$ = 4.33, S.D. = 0.78). Among the most highly rated aspects was the inclusion of pre-and post-learning self-assessment activities, which provided immediate feedback. This feature allowed learners to effectively evaluate their knowledge and understanding, achieving a high satisfaction score ($\bar{x}$ = 4.42, S.D. = 0.78).

Before and after engaging with the learning materials—through reading content, watching summary video clips, and viewing illustrations—learners could scan AR markers to complete self-assessment activities in the form of multiple-choice questions with five options. After selecting an answer, the program provided immediate feedback by reporting the scores. This functionality enabled learners to promptly assess their comprehension and progress.

This approach aligns with Yueayai (2019), who emphasised the principles of designing AR-based learning materials. Such designs should actively involve learners and provide instant feedback, allowing them to reflect on their actions and decisions. Immediate feedback helps learners understand whether their choices were correct, experience success, and receive positive reinforcement, fostering a more effective and engaging learning experience.

The findings of the research indicate that the instructional materials employed were designed based on brain-based learning principles, with the learning process structured in sequential stages. Additionally, augmented reality (AR) technology was integrated into each stage to facilitate learning activities. As a result, the use of instructional materials incorporating AR technology based on brain-based learning principles effectively enhanced learners' academic performance. Furthermore, it positively influenced learners' satisfaction with their learning experience using these materials.

4.3. Suggestions

i. Before implementing an instructional book using augmented reality (AR) technology, it is important to prepare both students and teachers in terms of technological knowledge and application techniques. This includes providing opportunities for students and teachers to experiment with the technology until they become familiar with it. This preparation helps prevent and reduce errors resulting from the use of the technology, leading to smoother and more convenient teaching and learning activities for both students and teachers.
ii. When designing learning activities using augmented reality (AR) technology, it is possible to develop formats that are engaging and challenging, and promote student participation in various ways. This could include incorporating 3D images, games, and other interactive elements.

5. Conclusion

The use of Augmented Reality (AR) technology as a framework for instructional media design, combined with brain-based learning principles, offers a transformative approach to education. Traditional teaching often depends on static materials such as text, black-and-white images, tables, and symbols, which may limit engagement. AR enhances these materials by introducing interactivity, enabling learners to perform self-assessments before and after lessons, watch video summaries, and engage in diverse learning activities. It also provides detailed visuals in vibrant 2D and 3D formats, making the learning process more dynamic and appealing. Research shows that most students express high levels of satisfaction with AR-enhanced media. Additionally, brain-based learning principles guide the instructional design process through structured steps, including pre-learning preparation, content presentation, video-based teaching, infographic summaries, and post-learning assessments. These steps have been shown to improve students' academic performance and engagement. AR technology not only facilitates interactive and effective learning experiences but also makes education more accessible, allowing students to gain knowledge anytime and anywhere. It supports both theoretical subjects and practical, skill-based learning, broadening its application across various fields. Moreover, the use of virtual formats minimises the need for printed materials and natural resources, making it an environmentally friendly solution. This innovative approach offers a sustainable and impactful direction for the future of education.

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