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Original Research Paper

AR CUBE SIM: An Augmented Reality Learning System for Food Web Education

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Abstract: This study aims to develop and evaluate an Augmented Reality (AR)-based learning system called AR Cube Sim for the topic of Food Ingredient in Grade 2 Science. Using the ADDIE instructional model and based on Constructivism Learning Theory, this application integrates the physical Merge Cube and the CoSpaces Edu platform to present interactive 3D visualizations. The application evaluation involved a sample of 21 respondents (15 students and 6 Science teachers) at SMK Bugaya, Semporna, Sabah. The results of the usability level test using the System Usability Scale (SUS) instrument showed an overall average score of 94.8% (Very Good/Grade A), where the teacher group gave a score of 98.6% and the student group 94.4%. The research findings prove that AR Cube Sim is effective in increasing student learning motivation (81.0%) and providing a fun and safe 3D visual manipulative learning experience (90.5%). This application has great potential to be formally integrated as a teaching aid (BBM) to support the modernization of digital education in schools.

Keywords: ADDIE, Augmented Reality, Food Puzzle, Merge Cube, Science Subject.

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1. Introduction

In today's modern times, the mastery and utilization of information and digital technologies is significant in various sectors, especially in the field of education. The education system in Malaysia has undergone a profound transformation in line with the Malaysian Education Development Plan (PPPM 2013–2025). The 7th shift of the PPPM specifically underlines the need to leverage information and communication technology (ICT) to improve the quality of teaching and facilitation (PdPc) nationwide. The impact of this digital modelling is increasingly evident following global challenges such as the COVID-19 pandemic which accelerated the implementation of learning based on digital media and online platforms. The integration of technology in the classroom is no longer just a flexible option, but a core demand in the era of the Fourth Industrial Revolution (IR 4.0).

The IR 4.0 framework encompasses nine main pillars, including automation, Internet of Things (IoT), artificial intelligence (AI), as well as Augmented Reality (AR) and Virtual Reality (VR). In a Science learning environment, AR offers the unique ability to overlay 3D virtual objects, animations, and computer-generated graphic elements onto real physical environments in real-time.The KSSM Science Form 2 Curriculum and Assessment Standard Document (DSKP) encourages the meaningful application of TMK to help students visualize abstract concepts. Based on this background, this study focuses on the development and evaluation of the application of an AR cube-based learning kit for the subtopic of Food Webs in Science Form 2.

Despite the introduction of various digital innovations, the practice of teaching Science in schools still faces a variety of fundamental pedagogical issues. Some of the key problems identified include:

1) Traditional Teacher-Centered Teaching Practices: Most Science teachers are still bound by conventional teacher-centered methods that are passive lecture-oriented, without a balanced emphasis on the cognitive, affective, and psychomotor domains. These methods frequently result in a decrease in students' interest and motivation to learn.
2) Difficulties in Understanding Abstract Science Concepts: Food Fabric and Ecosystem Topics involve energy flows, trophic stages, as well as complex dynamic interactions of organisms. Primary secondary students, especially in rural schools such as SMK Bugaya, Semporna, often face difficulties in visualizing these dynamic mechanisms if they rely only on static 2D diagrams in textbooks.
3) Lack of Interactive & Interactive Teaching Aids (BBM): Physical visual tools or replica models are often difficult to set up, cost-effective, not durable, or impractical to bring into the classroom [cite: 2]. Development of the AR Cube Sim Merge cube-based answer offers manipulative 3D visualization that is safe, practical, and immersive.

The scope of this study focuses on the subtopic of Food Supply (Ecosystem) according to the MOE Form 2 Science DSKP. The test was carried out at Sekolah Menengah Kebangsaan (SMK) Bugaya, Semporna, Sabah, involving a sample of 21 respondents (15 Form 2 students and 6 Science teachers). This innovation is of great importance to teachers (as an interactive teaching aid that enriches pedagogy), students (improving conceptual comprehension, motivation, and thinking skills), as well as educational institutions (supporting the modernisation of PdPc infrastructure in line with IR 4.0).

2. Literature Review

2.1. The Concept of Augmented Reality in Education

Augmented Reality (AR) is defined as an innovative technology that overlays digital information, such as 3D images, animations, sound effects, and text, directly onto real-world views of the physical environment [1]. In contrast to Virtual Reality (VR) which fully immerses users in a virtual environment, AR acts to enrich the existing environment by providing an additional layer of information without compromising the user's relationship with the physical realm. This technology allows digital entities and physical objects to interact in harmony, thus creating a hybrid learning environment that expands the boundaries of traditional teaching materials [2] [3].

AR provides a spatial learning environment based on three-dimensional visualization, something that conventional 2D printing materials fail to offer effectively [4] [5]. The ability to display abstract concepts or complex structures in the form of interactive 3D objects allows students to understand spatial relationships, scales, and orientations more deeply. The use of AR has been shown to be able to stimulate motivation, attract attention, and significantly improve students' understanding across cognitive and affective domains, as the learning process becomes more dynamic, responsive, and student-centered [6].

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Today's digital generation pupils learn far more effectively through integrated sensory experiences that include elements of hearing, vision, as well as physical and cognitive manipulation of objects. Through AR, 3D visual integration, audio guidance, and interactive controls allow multiple sensory channels to be driven simultaneously, which in turn reduces cognitive load and strengthens long-term memory [7]. This multisensory approach not only caters to a wide range of students' learning styles, but also builds immersive learning experiences that stimulate their curiosity and self-drive in a modern classroom [8].

2.2. Science Learning & Food Fiber Topics

The Science Secondary School Standard Curriculum (KSSM) is specially designed with the goal of building critical, creative, and problem-solving skills among students. Through an inquiry-based and scientific learning approach, KSSM Science aims to produce a generation that not only masters the facts of science, but is also able to analyze natural phenomena in depth and apply the knowledge to address real-world challenges [9].

Within this curriculum structure, the Food Chain subtopic under the Ecosystem Chapter plays a key role as it contains a variety of core concepts about environmental dynamics. This subtopic includes an in-depth understanding of the process of energy transfer through trophic relationships involving producers (green plants), multi-level users (herbivores, carnivores, and omnivores), as well as decomposers that maintain the cycle of organic matter in ecosystems [10].

A strong and comprehensive understanding of the concept of food webs is critical to enable students to appreciate the importance of ecological balance holistically [11]. When students understand how each organism is interdependent with each other, they will be more aware of the impact of environmental disturbances such as species extinction or habitat destruction on the survival of ecosystems and human life as a whole [12].

To overcome the challenge of teaching complex concepts, the use of Augmented Reality (AR) technology serves as an effective pedagogical platform [13]. AR technology allows abstract and interconnected nutritional relationships to be visually displayed in the form of a 3D dynamic food chain. This interactive simulation capability helps students see the energy flow and interaction of organisms in real life, thus enhancing their conceptual understanding and learning experience [14] [15].

2.3. Constructivism Learning Theory

The development of the AR Cube Sim is firmly based on the Constructivist Learning Theory pioneered by Jean Piaget and Lev Vygotsky [16]. This theory asserts that knowledge should not be passively transferred from teacher to student, but rather that students should actively build that knowledge through experience and direct interaction with their environment [17]. In the context of modern education, this theoretical foundation emphasizes the importance of providing a student-centered learning environment that promotes the translation of information concepts into meaningful self-understanding [18] [19].

Through the AR Cube Sim application, this principle of constructivism is translated into a practical way where students do not just read notes conventionally, but rather act as a physical Merge cube and manipulate the 3D simulation face-to-face [20] [21]. This combination of physical objects and digital displays creates a multisensory learning experience that allows students to control, rotate, and examine the structure of the object or simulation from various points of view, thus making the learning process more real and contextual [22] [23].

These interactive exploration-based activities provide space for pupils to connect their existing knowledge with new visual findings that are actively acquired [24] [25]. Through a process of self-inquiry and continuous discovery while operating the AR Cube Sim, pupils' cognitive load can be reduced while understanding of abstract concepts can be intuitively reinforced, which in turn forms long-term memory and effective learning [26] [27].

2.4. Existing Product Studies & Study Gaps

To ensure that the AR Cube Sim innovation has pedagogical uniqueness and superiority, a comparative analysis was conducted on three existing interactive media products [28] [29] [30].

Based on the analysis in Table 1, AR Cube Sim fills the study gap by offering multi-platform support, Merge Cube tangible object integration, as well as 3D ecosystem animation accompanied by interactive audio.

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Table 1. Comparison of Existing Systems vs. Proposed System

Features/ Aspects	BBM Solid Geometry II	AR Cardiac Anatomy	AR Cube Sim (Proposed)
Platform	PowerPoint 2003 (Limited)	Android App (APK)	Multi-Platform (Web, AR, VR, Mobile)
Interactivity	Click 2D screen / PowerPoint Animation	AR Marker / Gamification Quiz	AR Tangible Kiub Merge, Model 3D & Audio
Focus Topics	Form 2 Mathematics	Biology Matriculation	Science Form 2 (Food Fabrics)
Key Advantages	Visualizing basic 3D geometry	Interactive modules & practice quizzes	Dynamic ecosystem simulation, realistic audio & short notes

3. Methodology

3.1. ADDIE Study Design & Model

This study contains a quantitative study design based on the ADDIE (Analysis, Design, Development, Implementation, Evaluation) instructional model. The ADDIE model was chosen because of its systematic, phased framework, and proven to be effective in the development of technology-based media. The instructional phases are implemented as follows:

1) Analysis Phase: The researcher collected information through discussions with 3 Form 2 Science teachers to analyse the challenges of PdPc, the requirements of the DSKP curriculum, as well as the students' understanding gap on the topic of Food Supply.
2) Design Phase: Designing the structure of the storyboard, interaction flowchart, color selection, as well as the arrangement of notes and quiz questions based on Constructivism Theory.
3) Development Phase: Develop a 3D AR environment on the CoSpaces Edu platform, design graphics with Canva Pro and Freepik, and set up block coding (CoBlocks) for the Merge Cube integration.
4) Implementation Phase: Introduce the AR Cube Sim application to Form 2 Science teachers and students at SMK Bugaya, Sabah to be used in actual PdPc sessions.
5) Evaluation Phase: Assess the level of usability of the application through the distribution of the System Usability Scale (SUS) questionnaire form.

3.2. Study Sample & Data Collection Procedure

The sampling of the study involved a total of 21 respondents who were randomly selected stratified from SMK Bugaya, Semporna, Sabah. The sample consisted of 15 Form 2 students (71.4%) and 6 Science teachers (28.6%). Data collection was conducted using a Google Form which was distributed shortly after the AR Cube Sim-based PdPc session ended. Respondents were required to evaluate 10 usability items using a 5-point Likert Scale (1 = Strongly Agree to 5 = Strongly Agree).

3.3. Assessment Instrument & System Usability Scale

The study instrument was adapted from the System Usability Scale (SUS) framework by John Brooke (1986). The raw data were analyzed using the calculation of the percentage of SUS scores according to the standard benchmark range as shown in Table 2.

Table 2. Usability Score Rating Categories

Percentage Score Range (%)	Usability Level
> 80%	Excellent (Grade A)
70% - 79%	Baik (Good / Grade B)
50% - 69%	Boleh Diterima (OK / Acceptable / Grade C/D)
< 49%	Perlu Diperbaiki (Poor / Unacceptable / Grade F)

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4. Finding and Discussion

4.1. Respondent Demographics

Demographic analysis showed that out of 21 respondents, 6 were Science Teachers (28.6%) and 15 were Form 2 Pupils (71.4%). In terms of gender composition, 7 respondents were male (33.3%) while 14 were female (66.7%). The breakdown of demographic frequency is summarized as follows:

Table 3. Respondent Demographics

Category/ Variable	Sub-category	Frequency (n)	Percentage (%)
Respondent Type	Teacher	6	28.60%
	Students	15	71.40%
	Total	21	100.00%
Gender / Jantina	Male	7	33.30%
	Female	14	66.70%
	Total	21	100.00%

4.2. Interface

The main interface of this application is designed to ensure that users remain focused on the displayed AR elements. It contains navigation buttons that allow users to access various functions. In addition, an information panel is provided to give instructions or display the interaction status between users and AR objects, making the application easier to understand, especially for new users. The application utilizes the device camera to detect patterns on the Merge Cube and display 3D models in real time. The control features allow users to rotate or adjust the position of 3D objects simply by touching the screen. Additional elements such as animations and background sounds are also incorporated to create a more engaging and immersive interaction experience.



(a) **(b)**

Figure 1. Interface: (a) Main Interface, (b) Animation

From a design perspective, the interface applies a consistent arrangement of elements, colours, and icons to ensure that users can understand and navigate the application easily. The interface is also designed to be user-friendly, particularly for Form 2 students, with appropriate text sizes and button dimensions to provide a more comfortable and enjoyable learning experience.

Figure 2 illustrates the interface for the quiz page.

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Figure 2. Interface for the Quiz Page

4.3. Usability Analysis by Questionnaire Item

The usability testing of the AR Cube Sim app involved 10 evaluation items. The analysis of the feedback score for each item is shown in Table 4.

Table 4. Usability Analysis

Item	Usability Questionnaire Statement	Shoes 5 (%)	Results & Pedagogical Impact
Item 1	AR Cube Sim is easy to operate and use.	85.70%	User-friendly & intuitive interface.
Item 2	The audio can be heard clearly and in detail.	71.40%	Quality audio, little customization is required.
Item 3	The 3D object display clearly and accurately depicts the content.	76.20%	High quality 3D visuals & accurate DSKP.
Item 4	The use of the Merge cube is appropriate and safe for students.	90.50%	Physical cardboard cubes are very safe & practical.
Item 5	Suitable as a PdPc kit in the classroom.	85.70%	It has great potential as classroom fuel.
Item 6	The content contains a lot of useful information.	71.40%	Packed with ecosystem core information.
Item 7	Feel good about using this app.	90.50%	Immersive experiences stimulate positive emotions.
Item 8	Notes help with brief & deep comprehension.	66.70%	Mind maps help with conceptual understanding.
Item 9	Increase motivation to learn the Food Fabric subtopic.	81.00%	The impact of motivation and self-motivation is high.
Item 10	Suggestions for improvements are open.	Qualitative	Focus on topic addition & cube durability.

The following is an analysis of each point from a technical and pedagogical point of view.

Item 1: Usability and Handling of the AR Cube Sim

Item 1 evaluates the ease of operation aspect of the AR Cube Sim application which recorded a score of 85.70% for the highest scale option (Score 5). This high percentage proves that the majority of respondents found the software to be very user-friendly and operate intuitively without the need for complicated technical training. The simple and responsive user interface design allows users to get started with navigation quickly, thus reducing the technical gap during technology integration in the classroom.

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From a pedagogical point of view, this ease of use has a positive impact on the extraneous cognitive load of students. When the software is easy to operate, students' cognitive attention is not distracted by technical problems or confusing navigation, but can instead be fully focused on processing the content of the lesson. This intuitiveness allows the learning flow to occur naturally, where students can continue to interact with the material without hindrance.

In addition, this high level of usability gives teachers the confidence to position the AR Cube Sim app as one of the student-centered teaching modules. The ability of students to operate the app independently promotes autonomy in learning, stimulates exploration without fear of technical errors, and supports self-directed learning activities both inside and outside the formal classroom environment.

Item 2: Quality and Clarity of Audio Elements

Item 2 focuses on the user's perception of the quality of the audio elements which recorded a score of 71.40% for Score 5. While this percentage indicates that the majority of users are satisfied with the clarity and completeness of the audio provided, this score is among the modest in the overall findings. This indicates that while the auditory element works well to convey Science information, there are technical aspects that can still be streamlined.

In-depth analysis shows that audio quality plays an important role in supporting pupils with auditory learning styles. Clarity of pronunciation, dense narrative, and contextual sound effects help strengthen pupils' understanding of difficult Science terms. When audio is presented in detail, it acts as a secondary information channel that complements the visual display on the screen.

However, these results also give an indication of the environmental challenges during the implementation of PdPc. In an active and frequently noisy classroom environment, application audio can be interrupted if the volume is not adjusted correctly or if the device's hardware does not support clear enough sound output. Therefore, some adjustments are required in terms of volume control and the provision of subtitle functions.

As a pedagogical impact, improvements to audio quality will ensure inclusivity in multisensory learning. By streamlining audio channels to be clearer and more vibrant, the app not only supports the delivery of information based on Dual-Coding theory, but also ensures that no pupil is left behind due to the disruption of the classroom's varied acoustic environment.

Item 3: 3D Visual Accuracy and Curriculum Alignment

Item 3 evaluates the clarity and accuracy of the display of 3D objects in depicting the content of the lesson, where it recorded a score of 76.20% for Score 5. This evaluation reflects that the 3D visualization developed has good graphic quality and is able to accurately convey structures or organisms in three-dimensional form. This visual clarity is very crucial in the domain of Science teaching to avoid visual misconceptions.

In terms of curriculum coherence, the 3D visuals developed were found to comply with the requirements of the Curriculum and Assessment Standard Document (DSKP). The accuracy of these representations ensures that each 3D model such as the shape of an organism or physical structure accurately depicts biological reality, thus supporting the safe benchmarking of the quality of teaching aids in terms of the accuracy of scientific facts.

The main pedagogical impact of this item lies in its ability to transform students' spatial thinking. In conventional 2D printed materials, students often find it difficult to imagine the true orientation, depth, and size of an object. Interactive 3D displays provide students with the opportunity to rotate and examine objects from various angles, further strengthening conceptual understanding based on spatial visualization.

In addition, the accuracy of this 3D rendering acts as an abstract-to-concrete bridge. The experience of seeing vivid and detailed 3D models helps students build a strong mental schema. It makes Science learning more evidence-based visuals that facilitate understanding of complex environmental phenomena.

Overall, while a score of 76.20% is strong, there is room to further improve the texture and animation of 3D models in the future. Applying more dynamic interactive elements such as simulating organism movements, will allow the visual quality of the AR Cube Sim to achieve a more outstanding and immersive level of achievement.

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Item 4: Suitability and Safety of Using the Merge Cube

Item 4 recorded one of the highest scores in this assessment, at 90.50% for Score 5, which assesses the suitability and safety of using physical Merge cubes. This very high percentage shows the incredible acceptance from consumers of the integration of physical materials in the AR ecosystem. Physical cardboard cubes have proven to be a very practical, easy to hold, and suitable for students' physical development levels.

From a safety and practicality perspective, the cardboard material is lightweight and does not have sharp corners allowing it to be used safely in the classroom without the risk of injury. Additionally, the low preproduction cost of cardboard cubes makes it a high-impact and sustainable option for widespread distribution to pupils without the worry of costly hardware damage.

The pedagogical impact of using the Merge cube is particularly significant in stimulating kinesthetic and haptic learning. When pupils hold a physical cube while looking at the virtual environment on a screen, they experience simultaneous integration of the senses of touch and sight. This manipulative experience makes interaction with digital content feel real, safe, and highly conducive to an active PdPc environment.

Item 5: The Potential of AR Cube Sim as a Classroom PdPc Kit

Item 5 recorded a score of 85.70% for the Score 5 option, which confirms that the AR Cube Sim application is very suitable to be used as a Teaching and Learning (PdPc) kit in the classroom. Respondents see this application as not just a digital gaming tool, but rather as a Teaching Aid (BBM) that is ready to be formally integrated into the daily lesson plan.

This suitability is supported by a flexible application design and does not require complicated infrastructure setup. Teachers do not need to set up a sophisticated computer lab; it is enough to simply use mobile devices and Merge cubes. This mobility allows technology integration to occur spontaneously and effectively in any learning space.

From the point of view of pedagogical impact, the provision of the AR Cube Sim as a PdPc kit empowers an inquiry-based and student-centred learning approach. The teacher acts as a facilitator while the pupils actively explore the content through the kit. This situation transforms the traditional passive classroom atmosphere into a dynamic and collaborative learning environment.

Overall, this high score provides a benchmark that the AR Cube Sim has great commercial and pedagogical potential to be used as a standard BBM kit. It meets the needs of the country's digital education transformation that promotes the use of meaningful technology in daily PdPc.

Item 6: Density and Usefulness of Content Information

Item 6 measures the level of quality and usefulness of the app's content information, where it obtained a score of 71.40% for a Score of 5. These findings show that the majority of respondents agree that the content presented is useful and relevant to the Science topic studied. The app's content manages to concisely bring together key facts without containing excessive information that can confuse pupils.

The density of ecosystem core information in this application is designed to support the direct learning understanding of important facts. The information presented is focused on critical topics, allowing students to capture basic concepts such as energy transfer, the role of organisms, and trophic relationships more focusedly.

In terms of pedagogical impact, this simple but concise presentation of information avoids the problem of information overload. Pupils of the digital generation are more likely to absorb information in the form of bite-sized information supported by visual elements. This content structure facilitates the processing of information in working memory.

However, this score of 71.40% also indicates that the delivery of content can be further expanded. Some pupils or teachers may require a higher level of information depth for enrichment activities or assignments based on KBAT (Higher Level Thinking Skills).

Therefore, future improvements can include the provision of layered information. This allows pupils who need basic information to get short notes, while pupils who are at advanced levels can access additional information in a more in-depth way interactively.

Item 7: Levels of Fun and Immersive Experience

Item 7 recorded a joint highest score of 90.50% for Score 5, which indicates that pupils feel very much fun while using the AR Cube Sim application. This incredible percentage proves that the integration of

AR technology has succeeded in injecting elements of recreation and excitement into the Science learning process which is often considered abstract and rigid.

The excitement experienced by students stems from an immersive experience that stimulates positive emotions. Elements of visual reward, real-time interaction, and surprise when seeing 3D objects "appear" on a physical cube build a gamified learning experience. These positive emotions reduce learning anxiety and increase students' level of engagement with lessons.

The pedagogical impact of these findings is deeply rooted from the point of view of educational psychology. The positive emotions stimulated during PdPc directly drive interest in the affective domain, which in turn enhances cognitive focus. As students enjoy the learning process, their thinking becomes more open, curiosity increases, and knowledge absorption occurs more permanently and meaningfully.

Item 8: The Effectiveness of Notes and Mind Maps

Item 8 assesses the extent to which the notes provided help pupils understand briefly and deeply, recording a score of 66.70% for Score 5. This is the lowest score among all the items assessed. While this percentage still indicates a positive level of acceptance (more than half), it is a clear signal that the notes component is the area that needs the most overhaul and design improvement.

An in-depth analysis showed that notes in the form of static mind maps or overly brief texts may not be effective enough to convey Science concepts that require detailed explanation. Pupils found that while mind maps were helpful in terms of structuring basic conceptual structures, they remained limited in terms of providing a deep understanding of the complex mechanics of science.

From a pedagogical standpoint, these findings highlight the gap between interactive visual presentations (such as 3D models) and text-based note presentations. Users expect note presentations that are as interactive as AR visual elements, rather than just a regular text display that is moved into a digital screen.

Therefore, a suggestion for pedagogical improvement for this item is to transform plain text notes into series interactive notes, dynamic infographics, or self-paced quizzes (pop-up quizzes). This will ensure that the notes component can balance the needs of conceptual understanding in a concise and in-depth way more effectively.

Item 9: Increased Motivation to Learn the Subtopic of Food Fabric

Item 9 assesses the impact of the application on students' learning motivation, specifically for the Food Grid subtopic, which recorded a score of 81.00% for Score 5. This high score proves that the use of AR Cube Sim successfully injects self-drive and deep interest in students to learn this ecosystem topic more actively.

The Food Chain subtopic is often taught conventionally through static diagrams in textbooks. This approach often fails to show the dynamics of the relationship between nutrition and energy flow in life. The presence of AR Cube Sim changes this paradigm by allowing students to see food chains moving dynamically in 3D space.

From a pedagogical point of view, this increased motivation is closely related to Self-Determination Theory. This app gives students a sense of competence and autonomy as they control cube manipulation, which directly increases the intrinsic motivation to explore the subtopic without coercion from the teacher.

In addition, the impact of this motivation brings positive changes in terms of self-efficacy. Pupils feel more confident in their ability to understand difficult Science concepts because AR teaching aids provide visual support that reduces the abstraction of the topic.

In conclusion, this 81.00% increase in learning motivation proves that the AR Cube Sim is a very effective pedagogical tool in building an in-depth learning drive, especially for the Science subtopic that requires the visualization of complex interactions between organisms.

Item 10: Suggestions for Qualitative Improvement and Direction

Item 10 collects qualitative feedback based on open improvement suggestions from users. In contrast to previous quantitative items, this item provides a first-hand look at the actual needs of users in the field, with the main focus focused on two important aspects: the addition of new topics and the physical durability of the Merge cube.

Feedback on the addition of the topic shows that users see great potential in this app and want it to be extended across various other chapters in the KSSM Science curriculum. This reflects a high level

of satisfaction where users no longer want to limit the use of this AR technology to the Food Web subtopic only.

In terms of physical durability, the user's suggestion for improved quality of Merge cubes is very practical. Although physical cardboard cubes are very safe and inexpensive, repeated use by pupils in the classroom can cause them to deteriorate quickly, dent, or get dirty. The use of more durable materials such as compressed foam (EVA foam) or eco-friendly washable plastic is a recommended improvement step.

4.4. Summarize

The analysis of these qualitative items provides a very clear direction for the next phase of AR Cube Sim development. By expanding the scope of curriculum content and improving the durability of physical hardware, AR Cube Sim is capable of becoming a holistic, sustainable, and high-impact PdPc kit for long-term use in the education system.

The results of the calculation of the overall SUS score showed that the AR Cube Sim app achieved an average usability percentage of 94.8% (Grade A/Excellent). Breakdown by respondent group revealed the following findings:

1) Teacher Group: Obtained a usability score of 98.6% (Excellent). Teachers highly rated the app's ability to help deliver ecosystem concepts visually and systematically.
2) Student Group: Obtained an usability score of 94.4% (Excellent). Students report that manipulating 3D cubes makes learning Science much more enjoyable and easy to understand.

These findings are which proved that the use of tangible AR technology can reduce students' cognitive load, improve long-term memory, as well as create an active collaborative learning environment.

5. Conclusion

The study successfully met all three objectives of the study. The development of the AR Cube Sim based on the ADDIE model and the Theory of Constructivism proved to be effective in addressing the issues of traditional PdPc practices. The application successfully transformed the abstract learning method of the Food Web subtopic into a fun, interactive, and high-impact 3D manipulative visual experience. With the achievement of a SUS score of 94.8%, the AR Cube Sim was confirmed to have excellent pedagogical applicability.

The main advantages of the AR Cube Sim include multi-platform support, accurate 3D visualization according to DSKP, rich audio-visual interactions, as well as a significant increase in pupil motivation. However, some drawbacks have been identified, notably the reliance on physical devices of the Merge Cube, the requirement for the specification of smart devices that support AR, the internet network for early downloads, as well as the scope of content that is still limited to one subtopic.

Based on the qualitative feedback from Item 10 and the vulnerability analysis, the following suggestions for improvement are submitted for future studies.

1) Curriculum Scope Expansion: Developed the AR Cube Sim application to cover other abstract Science topics such as Circulatory Systems, Plant Anatomy, and Geology.
2) Markerless AR Mode: Develop an AR module without a strict reliance on physical Merge cubes so that they can be accessed by pupils who do not have cubes.
3) Offline Mode & Device Optimization: Provides a lightweight-sized version of the app that can run without internet access on low-spec devices.
4) Improved Physical Quality of Cubes: Using reinforced plastic materials or thick laminated cardboard to ensure the durability of physical cubes for long-term use in the classroom.

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