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ALHK: Integrating 3D Holograms and Gesture Interaction for Elementary Education

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Abstract The integration of technology in elementary education offers innovative ways to enhance learning. One such advancement is the use of three-dimensional holograms (3DH), which provide immersive displays that merge seamlessly with the learner's environment, creating a dynamic and engaging atmosphere. Educators have found that 3D visual tools significantly improve student comprehension, with 94.4 % agreeing in a preliminary study. However, using interactive 3D holography alone has limitations, such as the inability for students to physically touch or manipulate holographic objects. To address this, Active Learning with Holo-Kid (ALHK) is introduced as a desktop application for elementary school students (grades 1 to 6). ALHK combines Leap Motion technology's precision with interactive 3D holography to overcome these limitations. The combination allows students to interact with virtual objects in a more immersive and realistic manner. Holograms provide visual representation, while Leap Motion enables precise gesture recognition and hand tracking, resulting in a seamless and intuitive user experience. Initial evaluations demonstrate improved student engagement and comprehension. Future iterations aim to enhance scalability by incorporating features like custom object upload, multi-user interaction, and broader age applicability. ALHK shows promise as a tool for creating an immersive and intuitive learning environment using 3D holograms and interactive technology in elementary education.

Keywords: 3D hologram, Holo-Kid, Primary education, Virtual assisted learning, Leep motion.

1. Introduction

The evolution of educational methodologies has always been influenced by technological advancements. As we transition into an era dominated by digital immersion, the potential of integrating innovative technologies into elementary education becomes increasingly evident. Traditional pedagogical approaches, while effective in their own right, often face challenges in maintaining the engagement and interest of young learners, especially when introducing more complex or abstract concepts.

address the challenges of maintaining student engagement with traditional pedagogical approaches, the integration of advanced technologies could significantly enhance the learning experience for students. There have been various attempts to bring educational content to life through the use of digital multimedia software, such as educational kits. Several mobile apps, like 3D anatomy atlases, 3D bones and organs visualizers, and interactive internal organ models, have been developed to provide students with a more engaging way to learn. However, the interactivity offered by these apps is often limited to basic touch-based interactions, such as tapping and dragging. This type of interaction may not be particularly interesting

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or immersive for young learners, as it fails to truly enable them to visualize and experience the content in a meaningful way [32].

To overcome this limitation, more advanced technologies, such as holographic displays, could offer a transformative solution. Holographic technology has the ability to bring lessons and educational content to life in a remarkably realistic and immersive manner. By allowing students to interact with and visualize subject matter in three dimensions, the technology can foster deeper understanding, stimulate curiosity, and cultivate a more engaging and captivating learning environment.

Researchers have explored the use of holograms in education in the past. According to [18], Hologram technology is being used widely for educational purposes in museums and cultural content education. In addition, authors in [29] noted that holograms are used for demonstrations to overcome the physical limitations in classrooms. Studies in [31], also show that the use of holograms in education comes with benefits such as empowering students to collaborate better and actively participate in the learning process, as well as making learning more fun for students [7]. More importantly, holograms are effective teaching tools in that they help students to better understand the learning material, thereby leading to increased learning outcomes [17].

Meanwhile, the benefits of 3D holography in education are evident; however, its adoption in elementary education remains low. When considering the limitations of using 3D holograms alone, there are several reasons for the constrained immersive visual experience and limited interaction. First, users may not be able to physically touch or manipulate the holographic objects, which can restrict the depth of engagement and interactivity. This limitation can be addressed to some extent by combining 3D holograms with other technologies. Second, creating the content that is specifically designed for 3D holographic displays can be complex and time-consuming. Generating or converting existing 2D or 3D content into suitable holographic representations requires careful consideration of depth perception, parallax effects, and other visual cues. This process may involve specialized software and expertise [25].

To address these limitations, Active Learning with Holo-Kid (ALHK) is proposed. ALHK is a desktop application tailored to elementary school students (i.e., grades 1 to 6). ALHK combines 3D holography with leap motion technology. Leap Motion is a hand-tracking technology that allows students to interact with digital content using natural hand and finger movements. By combining Leap Motion with 3D holograms several benefits offered. For instance, (1) students are able to interact with virtual objects in a more immersive and realistic way. The holograms provide a visual representation, while Leap Motion enables precise gesture recognition and hand tracking, creating a seamless and intuitive user experience; (2) Leap Motion technology tracks hand movements and gestures with high accuracy. This natural interaction method eliminates the need for traditional input devices such as controllers or keyboards; (3) students also can grab, rotate, resize, or manipulate the holographic content with their hands, fostering a sense of direct control and interactivity. This active participation enhances the learning or user experience.

ALHK consider as cost-effective comparable to the traditional pedagogical approaches. The ALHK system has been designed to leverage commercially available and cost-effective hardware components, such as the Leap Motion controllers and standard computing devices. By optimizing the system requirements, the initial hardware investment per classroom can be kept relatively low, making it accessible for a wide range of educational institutions. The application can be seamlessly integrated into existing classroom setups, minimizing the need for extensive infrastructure upgrades.

This study aims to address the following key research questions:

1. How do elementary school teachers perceive the potential of 3D holography and Leap Motion technology in enhancing classroom learning?

2. How can the utilization of 3D holography in conjunction with Leap Motion technology improve student engagement across grades from 1 to 6?

The rest of the paper is organized as follows. In Section 3, relevant studies of the proposed application are discussed. Section 4 presents the methodology of the research. Section 5 presents the results and discussion. Finally, the conclusion and the future work of the study are given in Section 6.

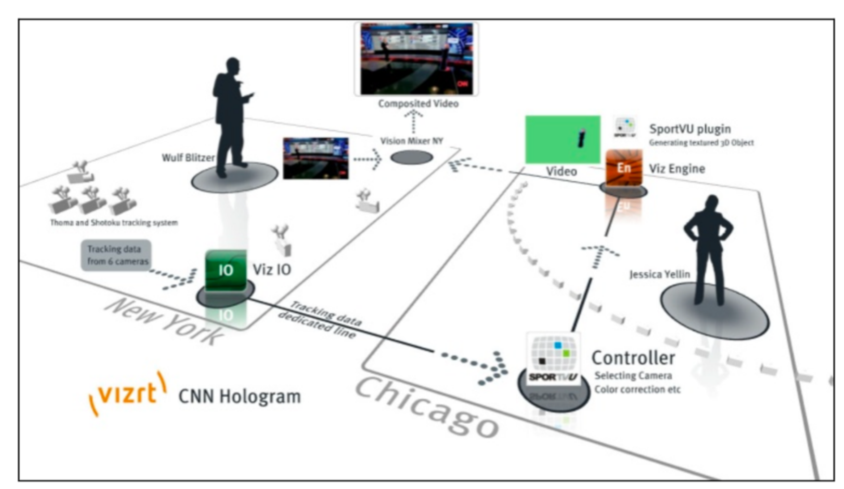


Figura 1: The CNN Hologram (adopted from [16]).

2. Background

2.1. 3H Holograms

3D Holographic Technology (3DHT) uses the interference of two light sources to create lifelike 3D images. A hologram captures a full, detailed view of an object by scattering one light source onto the object while illuminating it with another. This technology has advanced significantly since the 1960s and the invention of lasers, offering a realistic and immersive visual experience in various fields [20].

With advancements in technology, 3DHT has been increasingly utilized by scientists. This has even led to the ability to transport individuals from one location to another without physical travel (see Figure 1). In 2008, during the American elections, reporter Jessica Yellin in Chicago was "beamed up" into Wolf Blitzer's studio in New York, creating a remarkably realistic holographic display. This event attracted millions of viewers and the term "CNN Hologram" became a popular search term [16].

2.2. Leap Motion Controller

Leap Motion technology refers to a computer hardware sensor device that supports hand and finger motions as input, similar to a mouse, but without any physical contact. By using optical sensors and mathematical algorithms, the device can track the movement and gestures of hands and fingers with high precision. Then, it translates these movements into 3D space for computer interfaces or applications. This allows for a more intuitive and interactive way to control and navigate the software, especially in immersive environments like virtual reality or augmented reality [26].

3. Literature Review

Studies in [15, 19] delved into the potential educational value of 3D holograms in primary school settings. In particular, authors in [15] compared the impact of hologram-like pyramid projections on learning to that of conventional videos. With a sample size of 136 students aged between ten to twelve, the findings of the study revealed no notable differences between the two mediums concerning knowledge acquisition. Despite this, it was evident that the use of pseudo-holograms led to increased fun and motivation among students. Though these initial findings are promising, suggesting that these projections can foster positive learning experiences, the authors aptly note the need for more in depth studies to unearth ways to maximize the educational potential of the technology. Kim, Youbin and et al. [23]. presented the design of immersive learning resources with 3D holographic content to complement textbooks for elementary school students. A portable learning kit was developed using an Iterative Agile Prototyping process. Evaluation tests were conducted with students, teachers, and experts in EdTech, identifying strengths, weaknesses, and potential improvements. The study contributes to the future use of 3D hologram learning kits as universal teaching resources.

On the other hand, the study by [19] examined the influence of 3DH technology on students from grades one through three. Using a pretest and post-test design aligned with the primary school curriculum, the findings were statistically assessed. The results underscored the potential of 3DH technology, with a considerable 72 % of participating students displaying improved scores after their exposure to 3DH animations. This improvement was a testament to the enhanced knowledge absorption facilitated by holographic technology. Furthermore, the 3D hologram animations captivated the students, ensuring sustained attention and engagement.

Authors in [11] presented another dimension by introducing a low-cost 3D holographic display that can showcase both recorded and live sessions, which users can control with their fingertips. While the paper primarily focused on the technological aspects, it highlighted the applicability across various sectors, including education, medical imaging, and advertisements. Authors in [24] shifted the focus towards tertiary education, exploring the application of virtual tools in teaching Dynamics, a fundamental subject in Mechanical Engineering courses. Dynamics, which involves the study of the motion of particles and objects, has traditionally relied on 2D images and written descriptions. This study hypothesizes that visual representation can significantly aid students' understanding of intricate systems. In a comprehensive study conducted by the authors in [28], the impact of holographic teaching in physics classes at the higher education level was assessed. This mixed-methods study involved 311 students and introduced a model specifically designed to evaluate technology-enhanced learning spaces that incorporated a virtual-presence teaching tool. The quantitative findings indicated that holographic teaching did not have a significant effect on learning outcomes. However, it was observed that students exposed to holographic teaching experienced increased levels of flow during their learning process. Notably, student engagement levels remained consistent across both holographic and traditional teaching methods. Interestingly, sessions utilizing avatars demonstrated higher levels of social presence.

Further, a study in [10] examining the application of holograms in education, revealed that holograms have a positive impact on students' cognitive development. The use of holographic projections captures students' attention by providing multiple perspectives on a subject, leading to a better understanding of the material. However, implementing hologram technology faces challenges such as limited infrastructure, high costs, and a shortage of experts, as highlighted in the research [22].

To address these issues, researchers in [9] present an example of a pyramidal hologram designed for educational purposes. The hologram consists of a glass surface with a mirrored base, placed on a smartphone screen. This setup enables the projection of a three-dimensional object as a hologram, utilizing the reflection from the pyramid's mirror. Additionally, the authors propose incorporating hand gesture control for interacting with the holograms, enhancing the user experience.

In conjunction with holograms, augmented reality is often employed [12]. Individuals with learning or reading difficulties can utilize wearable devices like HoloLens virtual reality glasses to visualize and represent objects or locations described in books through holographic overlays.

Overall, the application of holograms in education shows promise for enhancing cognitive development, but challenges related to infrastructure, cost, and expertise must be addressed. For example, Holo-Study is limited to Microsoft's hologram lenses technology, making it accessible only to those who can afford it and use the Windows OS [2]. Hello Barbie [6] uses holographic technology but is mainly an entertainment device with set voice commands.

To consider the limitation, some studies combine the hologram with other technologies such as the pyramidal hologram and hand gesture control, along with the integration of augmented reality, offer exciting possibilities for immersive and accessible educational experiences. Chang and Chin Lai proposed a study that aimed to integrate 3D holographic imaging and hand gesture recognition technologies to create an interactive holographic imaging teaching aid system specifically designed for nursing education [13]. The objective was to enhance teaching effectiveness by providing an intuitive and control-based learning experience. The system was developed with practical application in mind, ensuring its relevance and usefulness in the field of nursing education. Both Virtual Piano and Blocks Game [5, 1] employs the leap motion controller, however, focusing on music and gaming respectively. The ALHK application uniquely integrates the Leap Motion controller with the 3DH, a distinctive combination that sets it apart within the elementary school learning environment

4. Research Plan

To achieve the purpose of the study, the use of ALHK as a mean to connect and integrate both leap motion and 3D hologram in education. The development of the ALHK involves a systematic approach which consists of four distinct stages: data collection and analysis, System architecture, design, and implementation. These stages were meticulously followed to ensure a comprehensive development process.

The development of the ALHK application followed a systematic approach to ensure a comprehensive and well-executed process. The first stage involved meticulous data collection and analysis, laying the foundational insights needed to inform the subsequent stages. This was followed by the definition of the system architecture, which provided the structural blueprint for the application. The design phase then translated these architectural specifications into a cohesive user experience and visual language. Finally, the implementation stage brought the entire concept to life through rigorous coding and testing. By diligently executing each of these distinct phases, the ALHK development team was able to deliver a comprehensive, well-crafted educational technology solution.

4.1. Requirements Analysis

Requirements analysis is conducted as first stage to identify the specific needs and expectations of elementary school teachers and students. The analysis aimed to ensure that ALHK would effectively shows how the active learning tool is important for students in grades 1 to 6.

The requirements analysis process involved gathering feedback and input from teachers who had experience with traditional teaching methods as well as some exposure to technology in the classroom. The primary objective was to understand their perceptions of the potential of 3D holography and Leap Motion technology in enhancing classroom learning. The teachers expressed a desire for more immersive and interactive learning experience that would capture and maintain students' attention and engagement.

4.1.1. Data collection, sample size and composition

This subsection explores the needs and expectations of the end-users, which are the elementary school teachers. It takes into account their feedback and emphasizes the importance of a user-friendly interface that enables easy navigation and interaction with the system. The teachers' requirements for their students highlight the desire for visually captivating and engaging experiences that promote active participation and hands-on learning.

The questionnaire-based data gathered from elementary school teachers helps inform the design and implementation of the system. The teachers requirements play a crucial role in shaping the overall user experience and ensuring that ALHK meets the needs of its intended teachers. Teachers are directly involved in the educational process and are the primary users of the ALHK application, leveraging it to explain concepts in a visually compelling manner. Their firsthand experience and insights are invaluable in assessing the potential and challenges of integrating the proposed app into their teaching methodologies.

A total of 90 elementary school teachers participated in the survey. This sample size was deemed adequate to provide a comprehensive understanding of the perceptions of teachers about 3D holography and Leap Motion technology as well as the potential challenges teachers could face in adapting the proposed application into their teaching methodologies.

4.1.2. Questionnaire design, analysis, and requirement elicitation

The questionnaire was designed to assess:

- Teachers' familiarity with the technologies associated with the ALHK app.
- Their willingness and perceived challenges in integrating such technologies into the educational process.
- Identification of content areas where students traditionally face comprehension challenges.

- The perceived potential of the ALHK application in facilitating educational content delivery for elementary students.

Some of the questions that were included in the questionnaire: (1) do you believe that students encounter difficulties in understanding scientific content, such as the shapes of planets?. (2) Is your objective to enhance the interactivity of the traditional learning process for students in the school?. (3) Do you believe that technology can significantly contribute to the success of the educational process?

The percentage of teachers who indicated that students do not face difficulties in understanding the shapes of planets is 33.3 %. On the other hand, 66.6 % of teachers indicated that students may encounter difficulties in understanding the planets. While 94.4 % of the responses indicated a need for the development of the traditional education process. Additionally, 97.8 % of teachers expressed that technology plays a crucial role in the success of the educational process. Consequently, the utilization of technologies like hologram and leap motion controller is expected to have a substantial impact on enhancing the educational process and facilitating better comprehension.

Furthermore, it was evident that a majority of teachers expressed willingness to utilize 3D images to elucidate concepts for their students. However, it was observed that teacher's level of using this technology was insufficient. Upon analyzing other responses for other included questions, it became evident that a significant majority of 94.4 % answered affirmatively, indicating that students have a better understanding when they engage with 3D images. This suggests that the interactive nature of 3D images facilitates comprehension and enhances the learning experience for students.

As a result, ALHK application functional requirements are specified and listed below:

- Content Creation Tools: Ability to create and customize 3D holographic educational content.
- Lesson Planning and Delivery: Deliver engaging and immersive lessons using 3D holograms and gesture-based interactions.
- Immersive 3D Holographic Experiences: students are able to (1) Interact with educational content presented in the form of dynamic 3D holograms; (2) Explore and manipulate virtual objects using natural hand gestures.
- Control the movement and manipulation of 3D holographic objects: Users can rotate 3D holographic objects by performing intuitive hand and finger movements. For example, placing two fingers on the object and rotating the hand will result in the 3D object rotating accordingly.

4.2. ALHK Architecture

Motivated by the system requirements and analysis, the architectural process of ALHK system is depicted in Figure 2, and explained as follows:

- Teacher Interaction: The process begins with the teacher opening the ALHK app on a computer. If it is their first time using the app, they are prompted to register and create an account. Once registered, they proceed to log in to the app.
- Section Selection: Within the ALHK app, multiple sections are presented, each containing specific objects or educational content. The teacher could choose a particular object from the selected section for display and interaction.
- Object Display: After selecting the desired object, the ALHK app displays it on the computer screen. This allows the teacher to preview and prepare the object for holographic visualization.
- Hologram Stage Setup: To view the object in holographic form, the teacher utilizes a hologram stage. This is achieved by mirroring or sharing the computer screen onto an iPad, typically using an application such as AnyDesk (i.e., a remote desktop distributed application).
- Visualizing the Hologram: The teacher places the iPad onto the hologram stage, enabling them to visualize the object in its holographic representation. This setup creates an immersive and interactive learning environment for the teacher and students.

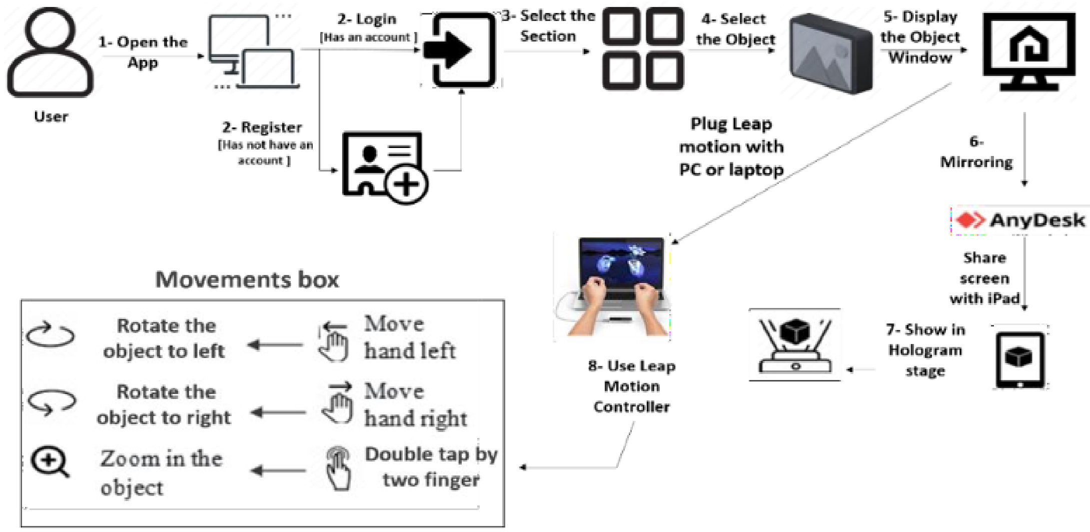


Figura 2: ALHK system architecture.

(a) 3D Hologram Display.

(b) Leap Motion Controller.

Figura 3: Human-Computer Interaction (HCI) technology.

- Movement Control: The ALHK system incorporates a leap motion controller, which is connected to the computer. This controller allows for precise hand and gesture tracking. The teacher or students can manipulate and control the movement of the object by utilizing the movements box.

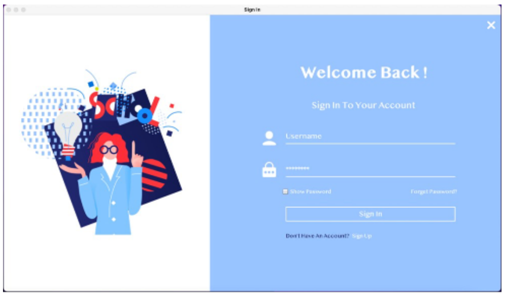
The ALHK system, which integrates 3D hologram (see Figure 3a), iPad, and leap motion controller (see Figure 3b), provides an interactive and engaging learning experience, enabling teachers and students to visually explore three-dimensional objects, manipulate them through hands-on interaction, engage multiple senses for enhanced comprehension, collaborate in a shared virtual space, and personalize their learning experience.

4.3. ALHK Framework

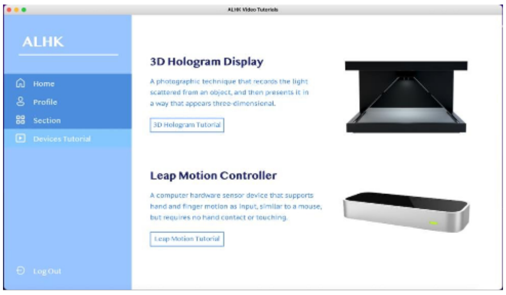
Designing a prototype for a system offers several benefits that allow designers to explore and validate specific features, meet user needs, and align with the overall system objectives. The ALHK prototype has been constructed to get feedback from potential users in the early stage. As shown in Figure 4, the ALHK prototype includes several interfaces, and each interface has unique functionality. For instance, (a) the profile interface provides a personalized space for users to manage their account settings; (b) the section interface categorizes different sets of objects. This intuitive interface streamlines the object selection process, allowing users to access the 3D objects quickly and easily; (c) the main-section selection interface shows objects in 3D, and users can effortlessly browse through a collection of objects and choose the specific ones they desire to visualize; (d) the resulting interface shows the 3D object visualization, where the chosen educational content is rendered in three dimensions, and ready for interactive exploration (more details are shown in Section 4.4).

4.4. Implementation

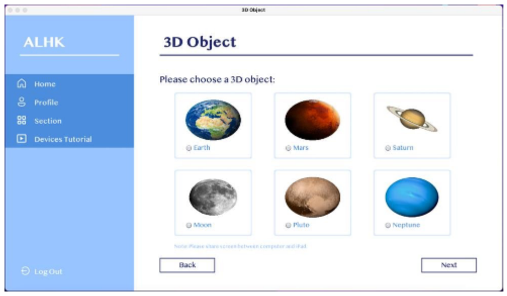
(a)



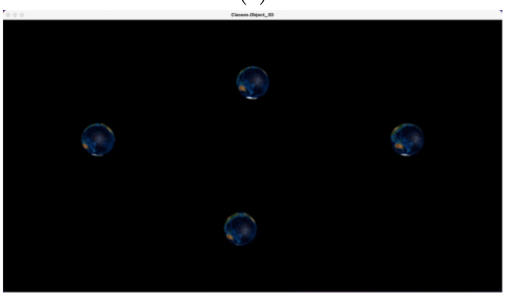
(b)



(c)



(d)



(e)

Figura 4: ALHK prototype interfaces.

Throughout the implementation phase, the critical components of the system were developed using the Java programming language. This encompassed the implementation of vital features including the registration and login functionalities, the 3D object interface, the seamless integration of the Leap Motion Controller, etc. By leveraging the capabilities of Java, these key components were successfully implemented, ensuring the system's functionality, user authentication, intuitive 3D object interaction, and seamless integration with the Leap Motion Controller.

- Main Functions: Upon receiving all the necessary user information, the sign-up function initiates and securely stores the provided data in the database, thereby facilitating the registration process (See Figure 4a).

- Sign-in function: The function collects the username and password entered by the user and performs a validation check to ensure their accuracy and correctness (See Figure 4b).

- Technology Overview: After the user successfully signs in, they are presented with a concise overview of the ALHK app's key components, namely the 3D hologram display and Leap Motion controller. This description is accompanied by illustrative figures that visually depict each technology. Additionally, the interface includes two buttons, namely "3D Hologram Tutorial.ªnd "Leap Motion Tutorial,"which, when clicked, provide access to video tutorials explaining the functionalities and usage of these technologies in detail (See Figure 4c).

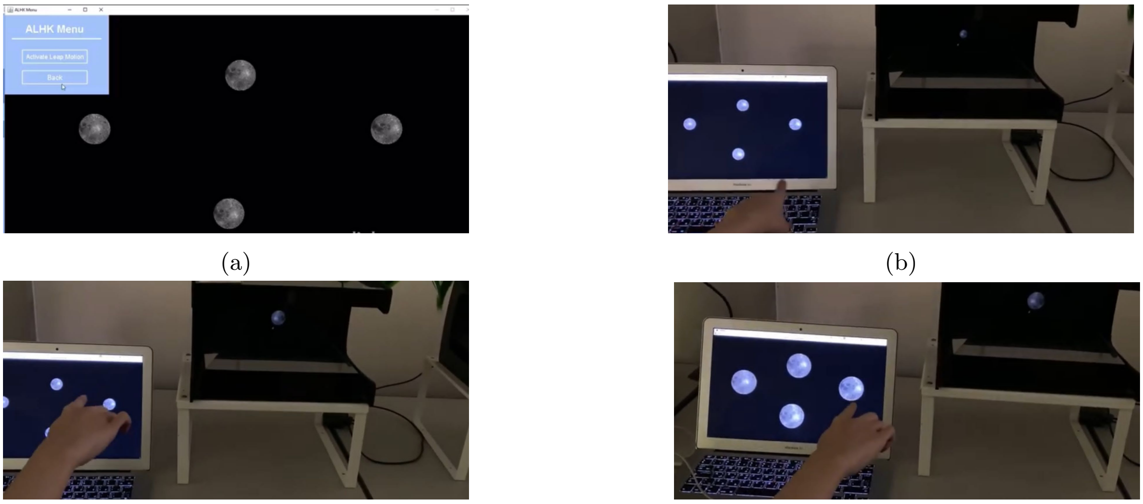
- Select the main section: Within the selection interface, all sections are efficiently stored in the database, ensuring easy restoration and retrieval. Presently, there exist two primary sections, with the flexibility to incorporate additional sections in the future as the need arises. This scalable approach enables the system to adapt and expand its sections to accommodate evolving requirements.(See Figure 4d).

- Objects Selection: The objects within the system are logically categorized and organized under their respective main sections. When users make their selection, the system dynamically displays the corresponding section, presenting a curated collection of related objects. This intuitive approach ensures that users can seamlessly access and explore the specific objects they choose within the context of their relevant sections. By structuring the content in this manner, the system enhances user navigation and facilitates a focused and coherent exploration of the objects. (See Figure 4e).

- Display 3D Object: the process of displaying a 3D object in the ALHK prototype involves three sequential steps:

  - **Step1**: Retrieving 3D URL from the database: The Database class employs a method to retrieve the URLs of all the 3D objects belonging to the selected section. According to the user's selection, the URL of the chosen object is assigned to the URL attribute within the Object_3D class. This step ensures that the appropriate URL is associated with the selected 3D object for display.
  - **Step2**: Setting up the layout: the ALHK utilizes the set Layout function to define the desired layout, ensuring optimal placement and arrangement of objects. Then, a Simple Universe object is created to serve as a container for other objects within the system. This container provides a framework for managing the 3D environment. After that, a canvas is generated to serve as the rendering surface for the 3D object. This canvas is then added to the Simple Universe, enabling the object to be displayed within the designated container. Finally, the ALHK sets up the view configuration, defining parameters such as camera position, field of view, and perspective. This step ensures that the object is displayed from the desired viewpoint and with the appropriate visual properties.
  - **Step3**: Object Creation and Lighting: The object is created by initially setting default transformation values such as scale, rotation, and translation. To enable the transformation to occur, the TRANSFORM_WRITE capability is enabled. This ensures that any subsequent transformations will be applied to the object. Additionally, the object is loaded using the scene object through the load method. The SceneGroup, which contains the loaded object, is added to a TransformGroup. This TransformGroup allows for further transformations and positioning of the object within the 3D scene. Finally, the TransformGroup objects are added to the BranchGroup, which serves as a container for all the scene elements. For proper lighting effects, the color and direction of the light source(s) are configured. This involves setting the desired color properties and specifying the direction from which the light illuminates the scene. This step ensures that the object is appropriately illuminated with the intended lighting conditions.

- Control Movement of 3D Object: As shown in Figure 5, the leap motion controller detects frames that capture hand movements, allowing each gesture to be stored and analyzed. By iterating through the hand object containing frame information, the system determines whether the user is utilizing their left or right hand. Following this, an if condition is employed to differentiate between clockwise and counterclockwise circular movements. When the user employs their right hand to perform a clockwise circle gesture, the object is zoomed in. Conversely, a counterclockwise circle gesture with the right-hand triggers the object to zoom out. Similarly, the object is rotated to the right when the user employs their left hand to perform a clockwise circle gesture. Conversely, a counterclockwise circle gesture with the left-hand prompts the object to rotate to the left. To handle different types of gestures, a switch statement is implemented. The predefined gesture type Çircleïs already enabled and recognized by the leap motion controller. In the switch statement, the system checks the type of each gesture. If a gesture is not recognized by the leap motion controller, the corresponding case in the switch statement is triggered, enabling appropriate actions or handling mechanisms for unrecognized movements.



(a) (b) (c) (d)

Figura 5: Engaging user interaction with ALHK in a dynamic and immersive learning environment.

However, there were a few challenges including:

- JDK Compatibility: The project required JDK 7 due to the Leap Motion Controller's limitations with later versions. This created an incompatibility issue with the MySQL connector. The solution was found in using MySQL connector version 5, which was compatible with JDK 7.

- Leap Motion Controller Movement: Discrepancies in the Leap Motion Controller's movement detection were attributed to its native library. The issue was resolved by integrating the Leap SDK's path into the VM options.

4.5. Testing and Evaluation

The testing phase plays a crucial role in the lifecycle of a project as it ensures the robustness of the software and the quality of the user experience. In the ALHK project, a comprehensive testing approach was adopted, which included unit testing, integration testing, and system testing. During the unit testing phase, the Junit framework [3] was utilized to evaluate individual code components. Integration testing involved testing high-level modules first, followed by low-level ones, and finally integrating all components together. Key tools and libraries employed in the testing process included the 3D Java library, the Leap Motion library, and the MySQL connector (see Figure 5).

In addition to code evaluation, assessing user experience was of utmost importance. To gather valuable feedback on various aspects of user experience, ranging from attractiveness and perspicuity to efficiency and dependability, the User Experience Questionnaire (UEQ) [4] was employed. This tool facilitated the evaluation and measurement of user satisfaction and provided insights for further improvements in the project's user experience.

5. Results and Discussion

In this section, the results of our research are presented and a comprehensive discussion that delves into the findings in detail are provided, offering a thorough analysis and interpretation of the data.

5.1. Data Collection

To address the research questions and meet the objectives, a survey was conducted among a selected group of teachers in Saudi Arabia. The data collection method employed for this survey was the administration of a questionnaire. As defined by Oates [27], a questionnaire consists of a predetermined set of questions that are answered by respondents to gather specific data. In this study, a questionnaire was distributed to 50 teachers employed in elementary schools.

5.2. Research Question One

The analysis of the responses to the survey conducted to achieve the first research question reveals the following:

1. Demand for Interactive Learning: 94.4 % of teachers expressed interest in making the learning process more interactive. This response shows a clear demand in the educational sector for tools that can enhance student engagement.

2. Openness to Technological Integration: 97.8 % of teachers would use an application that displays educational content as 3D images. This high percentage indicates that educators are receptive to integrating new technological tools in the classroom.

3. Need for Teacher Training: 87.8 % of respondents have not used hologram technology. This suggests a lack of exposure among educators to such tools, emphasizing the need for training.

4. Belief in Tangible Learning: 94.4 % of teachers believe interactive 3D images can enhance understanding. This indicates a strong preference for hands-on learning experiences that allow students to interact with and explore concepts directly.

5.3. Research Question Tow: ALHK Application Evaluation Using the UEQ

To assess the user experience of the ALHK application, the UEQ was employed. UEQ is a validated tool that assesses both usability and overall user experience [4]. UEQ was distributed via Google Forms to elementary school teachers who had interacted with the application. Out of the 50 responses received, over 70 % were from participants aged 44 and above, 14 % were between 34 and 43, and 12 % were between 23 and 33.

The UEQ results are shown in Figure 6 (mean values for various scales) and Figure 7 (benchmark diagram). Specifically, the mean values for the attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty scales are 2.50, 2.24, 2.42, 1.65, 2.36, and 2.21 respectively. Notably, all scales, except for dependability, scored in the .excellentrange, with dependability being rated as "good."

The UEQ categorizes its scales into two primary qualities:

- Pragmatic Quality: Task-related aspects, encompassing perspicuity, efficiency, and dependability.

- Hedonic Quality: Non-task-related aspects, including stimulation and originality.

For the ALHK application, the pragmatic quality score was 2.10, and the hedonic quality was 2.29, both nearing the .extremely good"benchmark. Overall, the positive UEQ score (> 0.8) underscores the favorable user experience the ALHK application offers. As a result, ALHK application provides an excellent experience to its users with a very high usability.

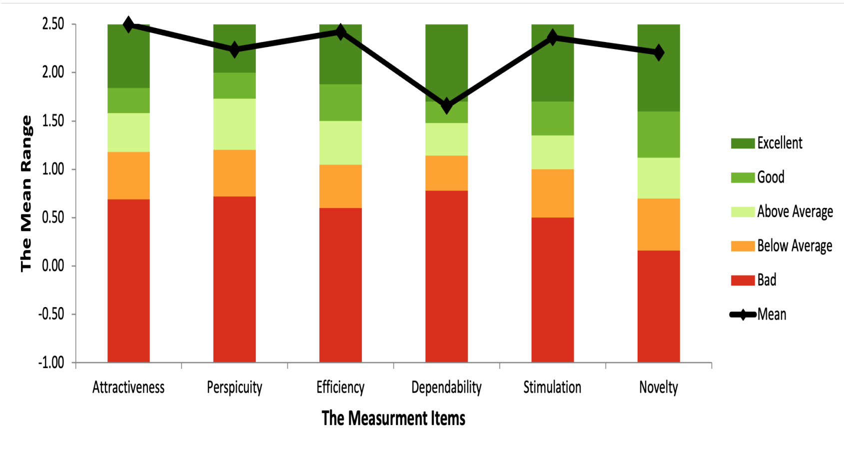


Figura 6: The mean for the UEQ scale values of the ALHK application.

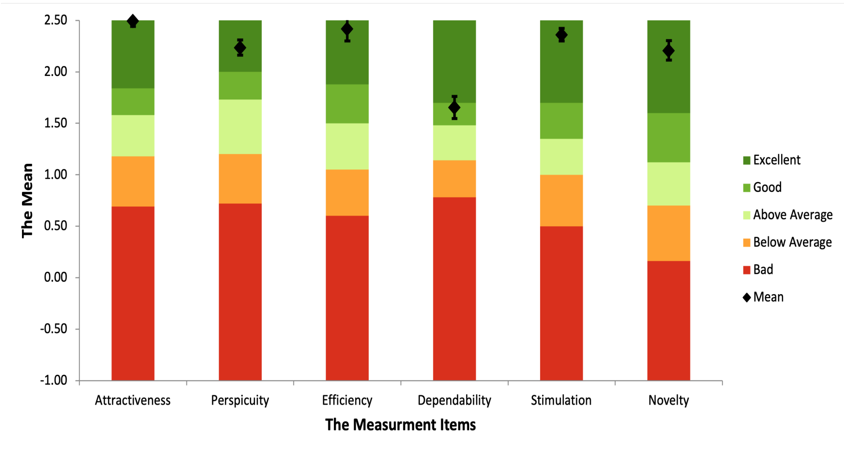


Figura 7: The UEQ benchmark diagram of the ALHK application.

5.4. Discussion, Limitation, and Future Work

The results obtained from the survey and evaluation provide valuable insights into the demand for interactive learning, openness to technological integration, the need for teacher training, and the belief in tangible learning among educators. These findings have significant implications for incorporating hologram technology, specifically the ALHK application, into educational practices.

The high percentage (94.4 %) of teachers expressing interest in making the learning process more interactive indicates a clear demand for tools that can enhance student engagement. This finding underscores the importance of integrating interactive elements, such as 3D images, into educational practices to meet this demand and create more engaging learning experiences. By leveraging hologram technology, educators can effectively address this need and provide students with interactive and immersive learning opportunities.

Similar findings were reported in other research studies [14, 30, 33]. For instance, Elmarash et al. (2021) highlighted the positive impacts of 3D hologram applications in education, noting how this technology facilitates student comprehension despite its cost. The authors emphasize the technology's applicability across all educational levels, from preschool to higher education [14].

Furthermore, while some teachers may resist implementing this technology due to fear [21], the current research study shows that an overwhelming majority (97.8 %) of teachers are willing to use an application that displays educational content as 3D images. This demonstrates a high level of openness to integrating new technological tools in the classroom. This finding highlights the potential for hologram technology, such as the ALHK application, to enhance teaching and learning experiences. Educators' receptiveness to adopting such tools creates an encouraging environment for the successful implementation of hologram technology in educational settings.

However, the significant percentage (87.8 %) of respondents who have not used hologram technology reveals a lack of exposure among educators to this type of tool. This finding, consistent with previous research by [8], emphasizes the importance of providing adequate training and professional development opportunities for teachers to familiarize them with hologram technology. By addressing this need, educators can gain the necessary knowledge and skills to effectively incorporate hologram technology into their teaching practices, thereby maximizing its benefits in enhancing student learning outcomes.

The belief among a majority of teachers (94.4 %) that interactive 3D images can enhance understanding reflects a strong preference for hands-on learning experiences. This finding aligns with the concept of tangible learning, where students can actively engage with and manipulate objects to deepen their understanding. By incorporating hologram technology that enables interactive and tangible learning experiences, educators can enhance comprehension and knowledge retention among students, catering to their preferred learning styles. Despite the high demand and openness to integrating technology in education, the usage rate of hologram technology remains relatively low worldwide. Many educators, as mentioned before, recognize that a significant number of teachers still feel unprepared to effectively incorporate technology into their classroom instruction.

The evaluation of the ALHK application using the UEQ revealed a positive user experience, with high ratings for attractiveness, perspicuity, efficiency, stimulation, and novelty. These findings highlight the highly usable and enjoyable experience provided by the ALHK application. The positive user experience further supports the potential effectiveness of the ALHK application in enhancing teaching and learning processes.

Overall, these results underscore the potential of hologram technology, particularly the ALHK application, in facilitating interactive and engaging learning experiences. The expressed demand for interactive learning, coupled with the positive user experience, emphasizes the importance of incorporating hologram technology into educational practices to enhance teaching effectiveness and student engagement. It is important to highlight that the main aim of this study is not generalizability but to propose a technology that would assist in enhancing learning activities. Addressing the need for teacher training can play a crucial role in supporting the successful integration of hologram technology into classrooms, benefiting both educators and students. By leveraging hologram technology effectively, educators can create immersive and interactive learning environments that foster student learning and engagement.

One primary challenge this research faced was participant recruitment during the design, data collection, and testing phases. A total of 140 participants voluntarily took part in this study. During the data collection phase, 90 teachers were engaged to help identify the functional requirements of the ALHK system. Additionally, 50 participants were involved in the testing phase, contributing to the evaluation of usability and overall user experience.

One of the main limitations of this study is the exclusion of elementary school students in the testing phase. As a future direction, after obtaining the necessary approvals, elementary school students will be involved in the testing phase to assess the ALHK system's usability and user experience, focusing on long-term effects, including learning retention and analytical abilities. Another limitation concerns the consideration of teachers' prior knowledge and experience, which may influence the results. Therefore, in future research, external factors affecting learning outcomes will be carefully assessed during the evaluation. Furthermore, additional measurements, such as user satisfaction, will be incorporated into the evaluation phase to provide a more comprehensive assessment. Additional future directions include expanding the scope of topics and objectives considered in the design of the ALHK system. Once all necessary tests are completed, it is essential to develop and implement professional training programs for educators to ensure their comprehensive understanding and effective integration of this promising technology. Lastly, a future research study will concentrate on analyzing the cost-effectiveness of ALHK to substantiate its proposed effectiveness.

6. Conclusion

The paper proposed a desktop application called Active Learning with Holo-Kid (ALHK) that combines 3D holography with Leap Motion technology to overcome the limitations of using interactive 3D holography alone. ALHK allows elementary school students to interact with virtual objects in a more immersive and realistic manner, improving engagement and comprehension.

The paper emphasizes the potential of 3D holography and Leap Motion technology in enhancing classroom learning and student engagement across different grade levels. The combination of these technologies provides a more immersive and intuitive learning environment for students. The use of 3D holograms enhances visual representation, while Leap Motion enables precise gesture recognition and hand tracking, allowing students to interact with virtual objects in a realistic way. Initial evaluations show improved student engagement and comprehension. Future iterations of the ALHK application aim to enhance scalability by incorporating features such as custom object upload, multi-user interaction, and broader age applicability.

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