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# Design immersive virtual reality (IVR) with cognitive conflict to support practical learning of quantum physics

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**ABSTRACT**
This research aims to design immersive virtual reality with cognitive conflict to support practical learning of quantum physics. This type of research is design research through the stages of needs analysis, product design, validity test, and practicality test. The needs analysis used questionnaire sheets distributed with Google Forms and obtained from 97 students. Immersive virtual reality design was developed by utilizing the Blender and Unity applications in the form of Android Package Kit (APK) format installed on virtual reality devices. The validity test involved six experts using validity instruments, and the practicality test involved nine students using practicality instruments. The validity test results on the learning and material indicators obtained a value of 0.89 in the valid category. A validity value of 0.95 was obtained in the valid category of the media aspect indicator. The average overall practicality score of the ease of use, display, design efficiency, and benefits indicators was 92 in the very practical category. The novelty of these research results is that they combine immersive virtual reality with cognitive conflict models applied to quantum physics learning that have been tested to be valid and practical.

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## Introduction

Significant technological developments in this decade have influenced various aspects of life, one of which is in the field of education. The transition from the era of revolution 4.0 to the era of Society 5.0 in the 21st century opens up golden opportunities for the world of education to integrate innovative and creative technology in the learning process (Mourtzis et al., 2022; Nair et al., 2021). Technological advances provide flexibility to carry out learning activities and interact socially without being limited by space and time (Shi et al., 2023).Advances in technology provide the possibility to conduct learning without the need for face-to-face. With technology constantly evolving, humans can interact with virtual objects close to their original experience (Cappannari & Vitillo, 2022).

Humans are now between the reality of the real world and the virtual world, where the boundaries between the two are increasingly blurred (immersive). The presence of the metaverse characterizes this condition as a virtual world. By utilizing virtual technologies such as augmented reality and virtual reality, humans can interact with their original conditions in a metaverse environment (Dwinggo Samala et al., 2023). Virtual reality consists of non-immersive, semi-immersive and immersive virtual reality (Mufit, Hendriyani, & Dhanil, 2023). Immersive virtual reality (IVR) is a technology that allows users to interact in a virtual environment. In IVR, the user's character is replaced by an avatar that replicates the user's real-world movements presented in a virtual environment. The combination of computer sensors, gloves, and headsets brings the users into a virtual environment and completely replaces the real world (LaValle, 2023; Raja & Priya, 2021a).

The development of augmented reality (AR) and virtual reality (VR) technology has significantly changed the educational process. In the last 21 years, AR and VR technology have become the focus of attention to be developed in supporting education (Marougkas et al., 2023; Samala et al., 2023). Advances in technology provide space for VR to be developed significantly into the realm of education and enable learning to occur in a virtual environment (Marougkas et al., 2024). This technology has been implemented in the form of media and teaching materials to support the learning process (Budi et al., 2023; Fortuna et al., 2023; Prahani et al., 2022)

IVR is used as a simulation media in health, training, entertainment, and education through the presentation of a virtual physical environment (Ansari et al., 2022; Barteit et al., 2021; Mäkinen et al., 2022). In the mass pandemic, the presence of IVR is one of the innovative solutions to support the improvement of learning quality (Prasetya et al., 2023). This innovative technology changes the pattern of human interaction that is bound and connected through technology, one of which is education (Al-Khassawneh, 2023; Xie et al., 2021). This technology is suitable for visualizing complex natural phenomena that are difficult to achieve in the real world (Di Natale et al., 2020).

The discussion of physics is related to real and abstract phenomena. Various problems are found in learning physics, including a poor understanding of concepts and misconceptions (Mufit, Asrizal, Hanum, et al., 2020). Not involving students in the investigation process is one of the causes. The availability of technology-based media plays a role in investigating abstract concepts (Puspitasari et al., 2021). In contrast, the essence of Physics is a field of science that studies natural phenomena through a process of investigation. Physics learning must involve students in the process of discovering concepts according to the characteristics of 21st-century learning. 21st-century learning involves discovery and inquiry (Festiyed et al., 2022). Not all experimental activities can be carried out directly at school. Expensive equipment costs and limited experimental equipment are challenges in investigating natural phenomena and experimental activities, thus requiring an alternative to simulating them (Price & Mohr, 2019; Soliman et al., 2021). The use of a virtual laboratory is an alternative to carrying out physics experiments without time and place limitations (Azma et al., 2022). The concept provides an opportunity to observe physical objects in the realm of very large and very small scale sizes.IVR is a technology that is able to replicate objects in size like the original but in a virtual environment. This technology allows in the learning process to observe and investigate objects on an atomic scale in the discussion of quantum physics materials (Fombona-Pascual et al., 2022; Maksimenko et al., 2021). IVR technology is suitable for use in education through more concise training and teaching (Kugurakova et al., 2021). The utilization of IVR aims to increase users' understanding of solving problems (Araiza-Alba et al., 2021; Soliman et al., 2021).

A cognitive conflict-based learning model is one of the learning models that provide stages based on presenting misconception problems experienced by students and then conducting investigations to find concepts and equations. The cognitive conflict-based learning model (CCBL model) has stages that aim to increase students' understanding of learning (Mufit et al., 2018; Mufit, Festiyed, et al., 2023). The phases of this model consist of activating preconceptions and misconceptions, presenting cognitive conflict, discovering concepts and equations, and reflecting (Mufit & Fauzan, 2019). The stages of the CCBL model present scientific problem-solving steps. Activation of preconceptions and misconceptions is a stage for acquiring students' initial knowledge of a phenomenon presented (Mufit, Festiyed, et al., 2023). In contrast, the presentation of cognitive conflict has a role in training students to think deeply to formulate the causes of a problem (Mufit, Asrizal, & Puspitasari, 2020; Saputri et al., 2021). The discovery of concepts and equations through experimental activities in the laboratory tries to train investigative and problem-solving skills to produce knowledge that follows scientific facts. Increasing understanding and constructing knowledge that follows scientific concepts is an advantage of CCBL model (Dhanil & Mufit, 2021). Presentation of cognitive conflict can train students' critical and creative thinking skills (Supena et al., 2021). Various teaching materials have been developed as a model support system, including interactive multimedia using Adobe Animate CC software (Aini & Mufit, 2022; Atmam & Mufit, 2023; Dhanil & Mufit, 2021). Besides, developing e-books and teaching materials using tracker software effectively increased conceptual understanding (Mufit et al., 2022; Mufit & Fitri, 2022).

The syntax stages of the CCBL model can also be implemented in virtual worlds through IVR designs, one of which is in quantum physics. The phenomena of quantum are abstract and complex physical material. Four experiments in quantum physics, including black body radiation, photoelectric effect, compound effect, and electron diffraction, are difficult to observe with the naked eye. The limitations of observations on a quantum scale in quantum physics learning provide a gap for researchers to present innovative learning by utilizing technology. Visualization of quantum physics objects like the original conditions is necessary to support the understanding of concepts. All forms of presentation of phenomena and real-world problems that are difficult to describe can be visualized through IVR (Di Natale et al., 2020). Phenomena that are visualized in three dimension (3D) form make it attractive for users to understand the problems (George-Williams et al., 2020). Previous researchers have developed quantum physics in the form of teaching materials by implementing a two-dimensional virtual laboratory (Noer & Mufit, 2023; Suyatna et al., 2019). State-of-the-art virtual technology allows the creation of virtual environments like their original state that allow users to observe, move, and interact with objects at the quantum scale. The presentation of quantum phenomena and experimental activities in the environment is part of the syntactic stages of CCBL model that can be presented in IVR. The stages of cognitive conflict-based learning models implemented in IVR environments are a novelty in quantum physics learning.

This study aims to develop IVR with cognitive conflict to support practical learning of quantum physics. In this study, the discussion is limited to needs analysis, product design, validity test, and practicality test of the products being developed. Thus, the research conducted aims to answer the following research questions:

1. What are the results of the need analysis of IVR with cognitive conflict to support practical learning of quantum physics?
2. How is IVR designed with cognitive conflict to support practical learning of quantum physics?
3. What are the results of the validity test of IVR with cognitive conflict to support practical learning of quantum physics?
4. What are the results of the practicality test of IVR with cognitive conflict to support practical learning of quantum physics?

## Methods

This type of research was design research through the stages of needs analysis, product design, validity test, and practicality test through the Plomp development stages (Plomp, 2013). This model presents simple and systematic stages in each step. The characteristics of this model are oriented towards the development of teaching materials and media that focus on learning. This is why this model was chosen to design or develop IVR products that are intended for learning.

The data collected in this study consisted of qualitative and quantitative data. Qualitative data were obtained from open-ended questions related to learning quantum physics at the needs analysis stage. Meanwhile, quantitative data was obtained from closed questions in needs analysis, validation results, and practicality. The target used to obtain information in the preliminary study was 97 first-year students majoring in physics at Universitas Negeri Padang (Padang State University). The information obtained in the needs analysis became the basis for developing IVR. The stages of research carried out are presented in Figure 1.

**Figure 1**

*Development plan*

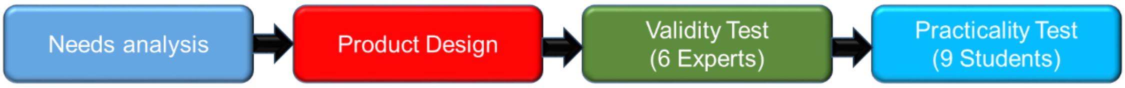



Figure 1. Displays the stages of the research flow, starting with the preliminary analysis stage as an initial data source for designing IVR. At the design stage, applications were determined to develop IVR. The applications chosen for designing IVR consist of Blender software and Unity software. Blender software was used to develop 3D objects, and Unity created an IVR environment with an output format in the form of an Android Package Kit (APK). All parts were checked and tried out (self-evaluation) before proceeding to test the validity and practicality. The validity test involved six experts (3 lecturers of quantum physics and 3 ICT lecturers). The six experts involved in product validation consist of professors and associate professors, who are lecturers who have taught and researched for more than ten years. Researchers are not involved as validators. The quality of expert expertise consists of assessing the suitability of quantum physics material, assessing the visualization of IVR layouts as a medium, and assessing the suitability of the application of learning models applied in a IVR environment. The validation instrument has been validated by referring to the indicators formulated by the Ministry of National Education (Kemendikbud, 2010).

## Participants

In testing the practicality of the product, direct testing is carried out on the target user. The intended target user by the design or development goals of this product is physics students. Nine students tested the product for practicality. The physics students involved consisted of four men and five women who were in the age range of 19-20 years. Each student is involved individually using the IVR product that has been designed and assessing the practicality of the product.

## Instruments and Data Analysis

Researchers developed instruments of needs, validity, and practicality analysis based on each indicator. Instruments in the preliminary research were 15 closed questionnaire questions with a rating range of 1 to 5 and 10 open questionnaire questions. Question indicators in needs analysis consist of problems in learning quantum physics, the learning approach used, and the urgency of IVR technology. The questionnaire was administered using Google Forms to get initial information on the needs analysis for using IVR in quantum physics. Validity and practicality instruments were used to obtain validity and practicality values. The instrument for IVR product validity consisted of four components, namely, materials' substance, learning design, visual communication displays, and software utilization (Kemendikbud, 2010; Mufit, Hendriyani, Usmeldi, et al., 2023). The basic general questions of practicality instruments involve four main indicators: related ease of use, display design, efficiency, and usability (Dhanil & Mufit, 2021; Mufit et al., 2022; Novitra, 2021). Needs analysis and practicality data were obtained from students, and validation data were obtained from experts who were processed using Microsoft Excel applications. The needs analysis data is grouped based on the percentage of the number of student answer choices in the assessment rating group in the range of 1 to 5. The validity data were analyzed through the following equation of V-Aiken.

$$V = \frac{(\text{Score From Expert - The Lower Score})}{(\text{Number of Category (Number of Expert - 1)})}$$

The results of the calculation of the scores were interpreted based on the Aiken index with a category of validity value of V<0.4 (low), 0.4≤V≤ 0.8 (moderate), and V≥ 0.8 (high) (Arikunto, 2013). The practicality data was obtained through a questionnaire in the form of a practicality instrument using a Likert scale. The results of the practicality assessment by the students were processed through the following equation.

$$N = \frac{\text{Score Student}}{\text{Maximum Score}} \times 100\%$$

The practicality assessment results were grouped into five categories, namely 0≤ P ≤20 (impractical), 21≤ P ≤40 (less practical), 41≤ P ≤60 (quite practical), 61≤ P ≤80 (practical), and 81≤ P ≤100 (very practical) (Novitra, 2021).

## Results and Discussion

### The Results of the Need Analysis of IVR with Cognitive Conflict to Support Practical Learning of Quantum Physics

A needs analysis was obtained through 15 questions using a Likert scale of 1 to 5 and 10 open questions. Answer choices consist of strongly agree (SA), agree (A), neutral (N), disagree (D), and strongly disagree (SD). The survey was conducted on 97 physics students at Padang State University using Google Forms. The questions presented sought to reveal problems, needs, and expectations related to physics learning. The results of the answer percentages of the 15 questions using a Likert scale are shown in Table 1.

**Table 1**

*The results of 15 questions were asked*

| No | Question Indicators | Frequency | | | | |
|---|---|---|---|---|---|---|
| | | SA | A | N | D | SD |
| A | Quantum Physics learning problems | | | | | |
| 1. | Quantum physics materials belong to abstract matter and are difficult to observe in the real world | 26 | 48 | 18 | 4 | 1 |
| 2. | The presentation of quantum phenomena is difficult to understand through images and explanations alone | 20 | 52 | 17 | 6 | 2 |
| 3. | Experimental activities are needed to improve the understanding of quantum physics | 60 | 33 | 3 | 0 | 1 |
| 4. | The books available today are not enough to understand quantum physics materials, so they need supporting media | 30 | 49 | 10 | 6 | 2 |
| 5. | The learning media available in learning today has not been able to present interactions such as real with quantum physics objects/phenomena | 9 | 47 | 28 | 10 | 3 |
| 6. | Visualization of videos, 3D objects, and real objects is needed in learning quantum physics | 56 | 38 | 2 | 0 | 1 |
| B | The Urgency of IVR Technology in Learning | | | | | |
| 7. | IVR is needed to visualize quantum physics phenomena and objects | 40 | 48 | 6 | 1 | 2 |
| 8. | IVR will interest and motivate you if applied to learning quantum physics materials | 47 | 46 | 3 | 0 | 1 |
| 9. | IVR technology is urgently needed to improve understanding of quantum physics | 43 | 45 | 7 | 1 | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 10. | IVR laboratory applications are needed to understand quantum physics materials repeatedly | 40 | 50 | 4 | 2 | 1 |
| C | Learning models/methods used in Quantum physics | | | | | |
| 11. | An investigation process in quantum physics learning has not accompanied learning activities and stages | 18 | 51 | 25 | 2 | 1 |
| 12. | The presentation of problems in learning quantum physics is needed to train critical thinking skills | 21 | 56 | 17 | 2 | 1 |
| 13. | An appropriate understanding of scientific concepts is indispensable in learning quantum physics, thus requiring CCBL model | 21 | 55 | 20 | 0 | 1 |
| 14. | Learning models/stages are very suitable for implementation in IVR | 25 | 55 | 13 | 2 | 3 |
| 15. | The current model/stage of learning (direct learning model with lecture/discussion/question and answer method), has not been able to improve understanding of quantum physics concepts | 23 | 42 | 23 | 8 | 1 |

Questions 1 to 5 in Table 1 reveal students' problems in learning quantum physics. More than 48 of students stated that learning quantum physics was classified as abstract and difficult to understand. Learning media and experimental activities were needed to support students' understanding of quantum physics material. Questions 6 to 10 inform about the need for IVR in learning quantum physics. More than 48 of students expressed their interest in IVR technology and stated that visualization of quantum physics material was suitable to be implemented in IVR and that a virtual laboratory in IVR was needed for observing and experimenting with quantum physics material. Questions 11 to 15 inform about the learning activities that students need. More than 48 of students stated that the stages of inquiry-oriented learning, presentation of phenomena, and encouraging the improvement of higher-order thinking skills were needed in quantum physics. In general, students' answers reveal the same meaning and intent of the goal. In open-ended questions, each student answered the ten questions accompanied by reasons. Student responses to answers to open-ended questions as a whole are presented in Table 2.

**Table 2**

*Open-ended questions*

| No | Questions | Respondents' answers |
|---|---|---|
| 1. | Have you ever used 3D applications such as games, augmeted reality, and IVR for games or learning? | Never used but know the technology |
| 2. | What do you think about applying IVR when applied to learning quantum physics? | Learning with IVR will encourage learning quantum physics to be more interesting |
| 3. | What do you think if the experimental activities of quantum physics are carried out in an IVR laboratory? | Helps to understand the material, creating a more exciting atmosphere in experimental activities |
| 4. | Do you think quantum physics learning is suitable to be visualized in an IVR environment? | Learning quantum physics is relevant to IVR because the material is abstract |
| 5. | What are the topics of courses related to quantum physics that need to be described more clearly in learning? | Photoelectric effect, X-ray production, Black body radiation, The Compton Effect |
| 6. | In your opinion, what is a good model or method to apply in learning to increase comprehension of | Learning is dominated by the lecture method |

| | | |
|---|---|---|
| | quantum physics material? | |
| 7. | What learning models/stages are well applied in learning quantum physics material? | Learning will be more systematic |
| 8. | What do you think about applying the learning model/stages in IVR to learn quantum physics? | Inquiry and discovery-oriented learning |
| 9. | Is the equipment for quantum physics experiments on campus fully available? | Not yet fully available for some specific materials such as x-ray production and others |
| 10. | What do you think about the presentation of objects in three-dimensional form compared to two-dimensional in floret physics material? | The presentation of objects in three dimensions is closer to real than two dimensions so that it will be easier if physical material is traced to 3D objects |

Table 2 shows tabulations of open-ended questions answered by students. The open-ended question response data came close to uniform results related to IVR technology, quantum physics, and experimental equipment. The first question revealed information that students had never used the technology but were familiar with IVR which is widely applied in interactive media such as games. The question reveals opportunities for the use of IVR to be developed as a medium in learning. The responses to the second and third questions inform students' interest regarding the application of IVR technology in learning quantum physics and as an experimental medium. Respondents revealed that observations of objects on a quantum scale would be more interesting and easy to learn.

In the fourth and fifth questions, learning quantum physics is relevant to be applied to IVR technology, because the material is abstract as in photoelectric effect material and X-ray production. In the sixth and seventh questions, eight students revealed that learning quantum physics material is predominantly presented through the lecture method. Learning quantum physics-oriented to the process of observation and inquiry will encourage learning to be more interesting. Presenting learning with sequence stages in IVR encourages interesting and systematic learning.

In the ninth question, revealing the availability of quantum physics experimental equipment is not as complete as in photoelectric experiments. In the tenth question, students expressed interest in presenting physical material in three-dimensional objects rather than two-dimensional. Students revealed that 3D objects are close to the original condition and the observation point of view is wider, thus encouraging the information obtained to be more complete. Overall, responses from respondents revealed the need for technologies that support quantum physics learning that are presented virtually, support the experimental process, and are presented systematically to support the understanding of concepts through the application of models that are appropriate to the learning orientation of the investigation.

The needs analysis results provided relevant information about the necessity of producing a virtual environment in quantum physics learning. The availability of equipment and textbooks currently used had not been able to give students an understanding to provide complex information on quantum physics material. Learning through presenting phenomena based on theory and experimentation was needed to give students a better understanding when studying quantum physics. Therefore, this needs analysis became the foundation for designing IVR on quantum physics materials.

### Design of IVR with Cognitive Conflict to Support Practical Learning of Quantum Physics

Based on preliminary research through needs analysis, it was found that quantum physics materials were classified as complex and required 3D object presentation. In addition, learning with orientation for experiment activities was most needed on quantum physics materials. The need for students for quantum phenomena presentations and investigations in a virtual environment to increase their understanding of quantum physics material required cognitive conflict-based IVR. Cognitive conflict-based IVR was designed using the Unity application. All objects and virtual environments were created separately through the 3D model application Blender. The virtual environments were explored via virtual headset hardware in the form of Oculus (Elmqaddem, 2019).

IVR was developed by utilizing Blender software and Unity software. Blender software was used to design all objects in the form of 3D models, while Unity software was used to combine all objects and create an IVR environment. The design stages of IVR development are presented in Figure 2.

**Figure 2**

*The process of creating cognitive conflict-based IVR*

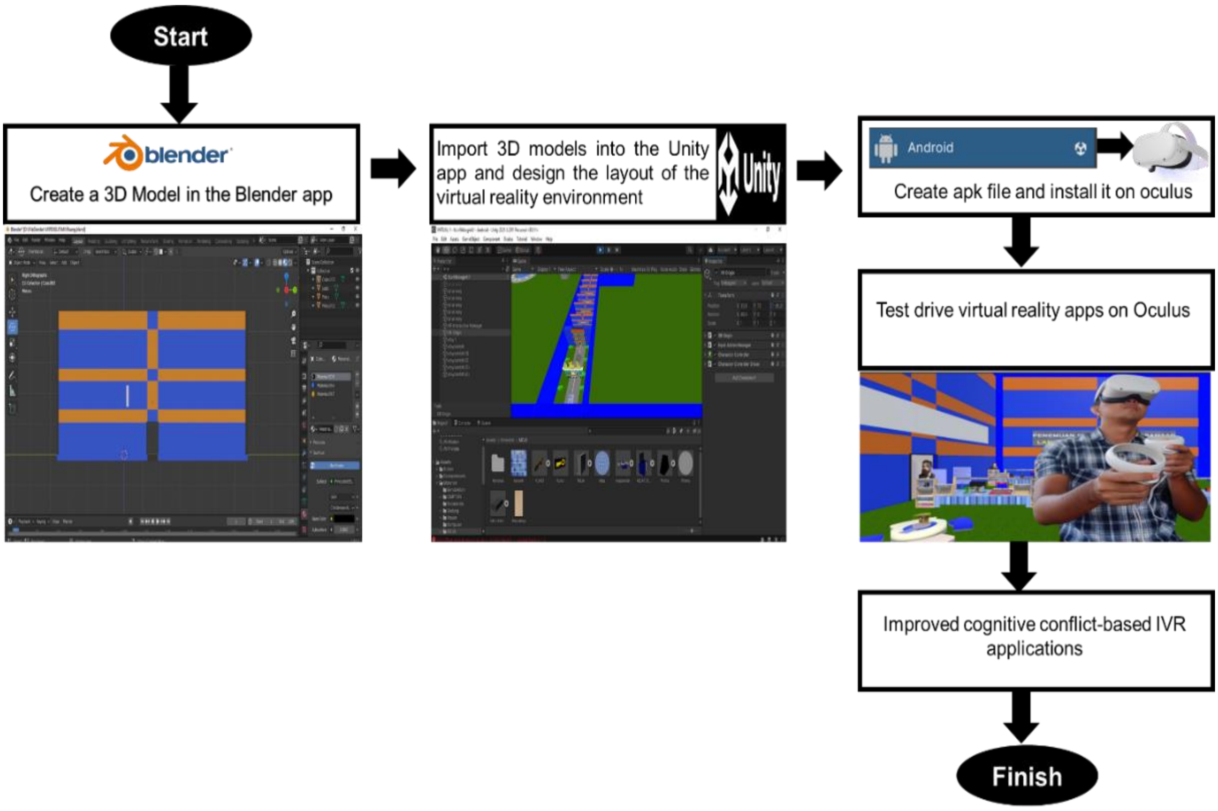
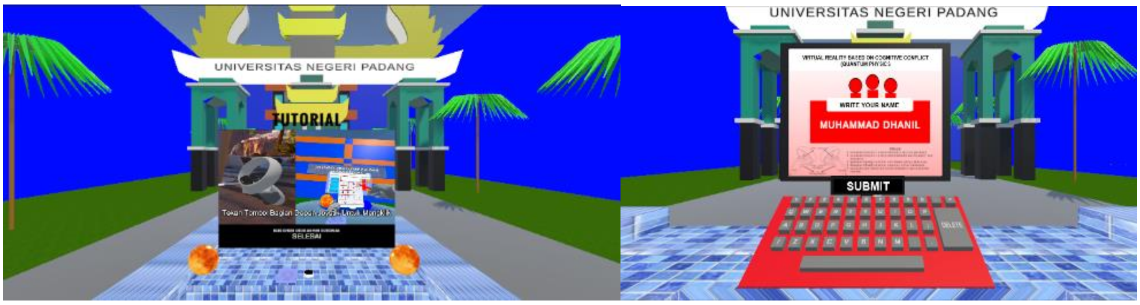



Figure 2 shows the first stage in designing a product was through 3D model design using the Blender application. All the objects needed in an IVR environment were designed separately. The 3D design of the model consists of buildings, tables, experimental equipment, and objects related to quantum physics phenomena. All designed 3D models were exported in the imported Filmbox (FBX) format and compiled in Unity. In Unity, a control system was built in the form of avatars that represent users interacting in a virtual environment. IVR environments and user avatars that have been developed in Unity are exported in Android Package Kit (APK) format with a minimum operating system of Android 6 (Marshmallow). The created APK is operated on IVR devices such as Oculus Quest 2. The developed IVR environment is displayed through IVR glasses and two controllers as avatar controllers in moving. In the IVR environment, several rooms were developed according to the flow of learning stages, CCBL model, and quantum physics learning materials.

In the early stage, instructions for using the Oculus Quest to explore the virtual world were presented by displaying a tutorial video on using buttons on the hand controller (Figure 3a). Furthermore, the users or students wrote down their identities so that they could continue the next activity (Figure 3b). Users' identities were important for teachers in identifying every student who carried out the activities in the IVR world.

**Figure 3**

*(a) Design of instructions and tutorials for using Oculus (b) User identity design*

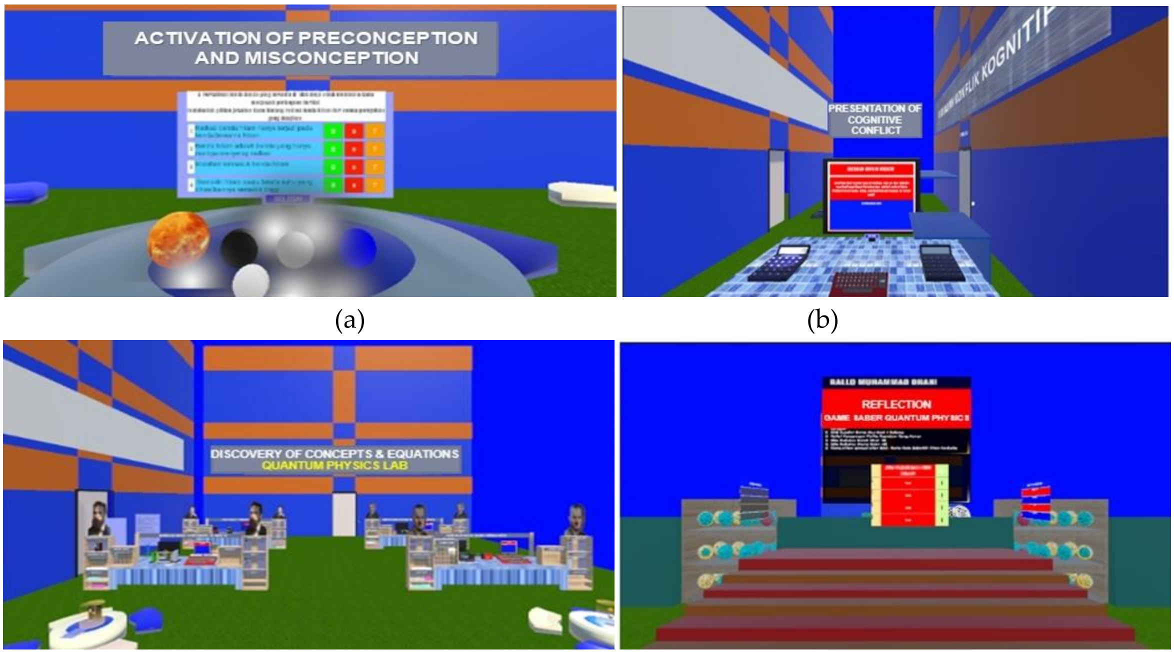



(a) (b)

The display of the developed IVR environment was constructed based on the CCBL Model stages, as shown in Figure 4.

**Figure 4**

*IVR environment design; (a) activation of preconception and misconception, (b) presentation of cognitive conflict, (c) discovery of concept and equation, (d) reflection*




(a) (b)

(c) (d)

Figure 4 shows the each stage of the CCBL model was designed as separate rooms and accessed sequentially to the next room. This design aimed to guide users/students to learn through scientific steps based on the syntax of the CCBL model. The study of quantum phenomena included black body radiation, photoelectric effect, Compton effect, and x-ray production, which were presented relevant in each syntax CCBL model. In the preconceptions and misconceptions activation room, students' activities were designed to examine/check their prior knowledge about quantum physics by providing some simple problems in 3D objects. The presentation of 3D objects in a virtual environment aimed to help students remember phenomena close to the everyday environment that were closely related to quantum physics. Students' initial understanding was shown through their answers about the phenomena presented in the virtual environment. The results of students' knowledge could be recorded as a data comparison, as in previous research (Dhanil & Mufit, 2021).

In the cognitive-conflict presentation room, IVR was designed to provide quantum phenomena that trigger students to think deeply and encourage curiosity. The syntax for cognitive conflict presentation could stimulate students' thinking by demonstrating conflicting phenomena (Mufit, Asrizal, & Puspitasari, 2020; Saputri et al., 2021; Supena et al., 2021). Students were allowed to propose hypotheses from the quantum phenomena displayed in the virtual environment. The hypothesis was tested in the next stage, namely the concept discovery and equation room created as a laboratory room. Experimental activities were designed to increase students' knowledge (Mufit et al., 2022; Mufit, Festiyed, et al., 2023). In this room, students carried out experiments using virtual laboratory equipment. Each set of experimental equipment was equipped with manuals, additional information, a data cabinet, and the equipment arranged on a virtual laboratory table (Figure 5). Users could hold and touch all objects while doing experiments in the real world but carried out in a virtual environment (Coiffet & Burdea, 2017).

In the reflection room, activities were designed to restate all the results of students' knowledge from the previous stages and restructure the understanding they obtained. After having a complete understanding, students continued to do comprehension test activities through quiz games in a virtual environment. The reflection room aimed to review the achievement of students' conceptual understanding (Mufit & Fauzan, 2019). The reflection results were conclusions of all stages and scores of comprehension tests, which were then presented to teachers and classmates in the real world. The designed IVR prototype was self-evaluated by looking at the completeness of the four CCBL model syntaxes applied, the entirety of the four quantum phenomena experiments, the suitability of core competencies, basic competencies, objectives, and indicators with quantum phenomena material. In addition, it also checked the clarity of language and the accuracy of the learning sequence. In the IVR laboratory, four sets of quantum physics experimental activities are presented as presented in Figure 5.

**Figure 5**

*Experiment room design, (a) blackbody radiation experiment, (b) photoelectric effect experiment, (c) Compton effect experiment, (d) x-ray production experiment*

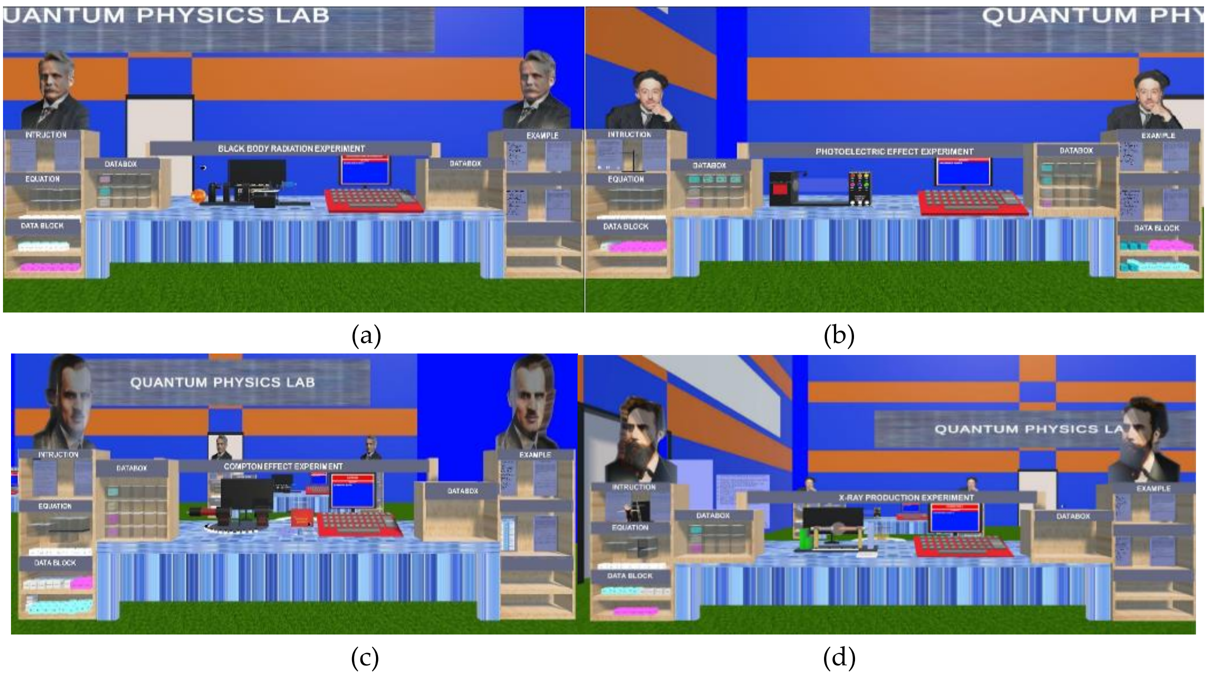


Figure 5 quantum physics experimental activity equipment consisting of tables, cabinets, experimental equipment, computers and data cabinet. Experimental activities in IVR allow users to walk and touch the equipment. The laboratory table serves to place equipment and supporting objects in the laboratory. Computers are used to compile the results of experimental conclusions. Quatume physics experimental equipment is built based on replicas of these equipment in the real world. IVR laboratories are successfully developed with all equipment and allow users to experiment in real environments.

## The Results of The Validity Test of IVR with Cognitive Conflict to Support Practical Learning of Quantum Physics

The results of the IVR product validation that was developed include learning aspects, materials, and media aspects. Learning indicators and materials explain quantum physics learning materials and the learning models used. The media aspect indicators include Visual Communication Display and Software Utilization. Validation of learning and materials involves three experts. The intraclass correlation coefficient test results on the learning and material indicator obtained an average measurement result of 0.631 at medium reliability. These results, indicate good agreement among experts. The results of the validity of learning and materials are presented in Table 3.

**Table 3**

*Learning and material results validity*

| No | Learning and Material | V1 | V2 | V3 | Average |
|---|---|---|---|---|---|
| 1 | Material Substance | 0.88 | 0.88 | 0.88 | 0.88 * |
| 2 | Learning Design | 0.91 | 0.90 | 0.92 | 0.91 * |
| | Average | | | | 0.89 * |

*Note.* * Valid, V1: Expert 1, V2: Expert 2, V3: Expert 3

Table 2 presents valid results from learning and materials related to material substance and learning design. The average validity score on material substance is 0.88 in the valid category. In the learning design, an average score of 0.91 was obtained in the valid category. Overall, the average result of learning and material validation was 0.89 in the valid category. In addition, the media aspect validation is validated by three different experts. The results of the intraclass correlation coefficient test on the Media Aspects indicator obtained an average measurement result of 0.559 at medium reliability. These results, indicate good agreement among experts. The validation results for the media aspect are presented in Table 4.

**Table 4**

*Media aspects results validity*

| No | Media Aspects | V1 | V2 | V3 | Average |
|---|---|---|---|---|---|
| 1 | Visual Communication Display | 0.98 | 0.97 | 0.99 | 0.98 * |
| 2 | Software Utilization | 0.93 | 0.89 | 0.92 | 0.92 * |
| | | | | | 0.95 * |

*Note.* * Valid, V1: Expert 1, V2: Expert 2, V3: Expert 3

Table 4 presents valid results from learning and material related to visual communication display and software utilization. The average result of the validity score on media aspects is 0.88 in the valid category. In media aspects, an average score of 0.91 was obtained in the valid category. Overall, the average result of media aspects validation was 0.95 in the valid category.

Buttons, layout, font, color, arrangement of objects, and feedback that function properly are conditions for the product to be used (Akman & Cakır, 2019; Schultz, 2005; Sherman & Craig, 2018). Display aesthetic design is an essential concern for technology users (Tarasewich, 2003; Tractinsky, 2004). These results are similar to spatial planning and button functionality in IVR development in virtual environments (Dinis et al., 2017; Paszkiewicz et al., 2021). The utilization of software is a crucial indication of the characteristics of a product being developed (Abichandani et al., 2019). Software utilization determines the final result of the product being developed. The software utilization indicator obtained a value of 0.92 in the high validity category. The average value of the four aspects of validity was 0.94 in the criteria of high validity. Next, the valid IVR was then tested for practicality.

## The Results of the Practicality Test of IVR with Cognitive Conflict to Support Practical Learning of Quantum Physics

Based on the stages of the Plomp development model, practicality testing is one of the important stages involving testing products developed on a limited scale. The practicality test of IVR products was conducted on nine first-year students of Padang State University majoring in physics who enrolled in the Basic Physics course. Student sampling was based on grouping students with low, medium, and high academic abilities. The selection of sample testing with various competencies aims to obtain good results when different participants use the product and have varying levels of competence. Figure 6. Shows practicality testing activities by using Oculus Quest 2 to explore virtual environments.

**Figure 6**

*Practicality test of IVR applications use*

After the students conducted the product trials, they evaluated the products using an assessment questionnaire. Practicality assessment consisted of four aspects: ease of use, display design, efficiency, and usability. Each feature was elaborated into several practical indicators. Table 5 and Table 5 show the indicators of ease of use and display design aspects.

**Table 5**

*Validity results*

| No | Indicator | Score |
|---|---|---|
| 1. | VR instructions are easy to understand. | 96 * |
| 2. | The Joystick navigation menu in VR is easy to use. | 96 * |
| 3. | The material presented is easy to understand. | 91 * |
| 4. | The material presented is easy to understand. | 89 * |
| 5. | The 'presentation of cognitive conflict' stage is understood, explored, and implemented. | 84 * |
| 6. | The 'finding concepts and equations' stages are easy to understand, explore and implement. | 96 * |

| | | |
|---|---|---|
| 7. | The 'reflection' stage is easy to understand, explore and implement. | 91 * |
| 8. | Virtual lab experiment activities are easy to understand, explore and implement. | 91 * |
| | Average | 92 * |

*Note.* * Very practical

**Table 6**

IVR *display design indicator*

| No | Indicator | Score |
|---|---|---|
| 1. | The start page of the IVR view is unique and attractive. | 93 * |
| 2. | Interesting display of IVR content. | 91 * |
| 3. | Interesting IVR typefaces. | 91 * |
| 4. | The 3D objects that are displayed are interesting | 98 * |
| 5. | IVR provides a virtual world experience that feels like the real world | 91 * |
| 6. | IVR creates an interaction between the user and the virtual world | 96 * |
| | Average | 93 * |

*Note.* * Very practical

The highest score in the user-friendly aspect was 96 on the indicators of instructions, menus, and concept discovery, and the lowest score was 84 on the indicator of cognitive conflict presentation. The average ease of use aspect score was 92 in the very practical category. Meanwhile, in the display design assessment, the highest score was 98 on the 3D objects indicator, while the lowest was 91 on the font selection indicator. Overall, the average score for the visual display feature was 93 in the very practical category. Furthermore, the results of the evaluation of efficiency and benefit aspects are shown in Table 7 and Table 8.

**Table 7**

*IVR display design indicator*

| No | Indicator | Score |
|---|---|---|
| 1. | IVR streamlines learning time to be effective. | 89 * |
| 2. | IVR is cost-efficient because it does not require an internet network. | 91 * |
| 3. | IVR streamlines labor in performing maintenance on virtual instrument equipment | 91 * |
| | Average | 90 * |

*Note.* * Very practical

**Table 8**

*IVR benefit indicator*

| No | Indicator | Score |
|---|---|---|
| 1. | IVR can be used for independent learning | 96 * |
| 2. | IVR makes it easy to understand concepts | 89 * |
| 3. | IVR can be used as a substitute for relatively expensive laboratory equipment | 91 * |
| | Average | 92 * |

*Note.* * Very practical

Each indicator assessment was very practical based on the evaluation results of the efficiency aspect of using IVR. The highest score was 91, while the lowest was 89, with the overall average value of efficiency indicators being 90 in the very practical category. On the benefit aspect, the highest score was 96 on the independent learning indicator, and the lowest was 89 on the concept understanding indicator. The overall average score for the benefit aspect was 92 in the category of very practical. Table 9 shows the overall average results of the practicality test.

**Table 9**

*Practicality test indicator*

| No | Indicator | Score |
|---|---|---|
| 1. | Ease of Use | 92 * |
| 2. | Display Desgin | 93* |
| 3. | Effeciency | 90* |
| 4. | Benefit | 92 * |
| | Average | 92 * |

*Note.* * Very practical

The score for ease of using IVR was 92 in the very practical category. Presentation of tutorials on using IVR in the form of written instructions and videos in a virtual environment helped students understand how to use it. Providing manuals in media assisted users in exploring the products being developed (Ros et al., 2020). Students explored the virtual environment, examined all objects, and checked all the buttons in IVR, as shown in Table 9. The practicality of the display was considered very good by students. The room layout, color choice, button functionality, and legibility made it attractive to the users. A simple and proportional display design increases interest in students (Di Natale et al., 2020; Parong & Mayer, 2018).

IVR was based on cognitive conflict and has been designed to bring novelty to learning by including the stages of cognitive conflict models, presentation of phenomena, and IVR laboratories. Combining IVR with the CCBL model is an innovation in this research. The four syntaxes of the CCBL model direct students to realize their misconceptions or prior knowledge and get the correct concept through a process of inquiry (Mufit, Festiyed, et al., 2023). Previous researchers presented cognitive conflict models in the form of digital teaching materials that were limited to the presentation of sentences in guiding the implementation of learning (Mufit, Hendriyani, Usmeldi, et al., 2023). IVR creates a systematic learning experience by presenting each syntax, a model of cognitive conflict, in the form of specific rooms. Each room presents 3-dimensional objects that represent activities from the stages of the CCBL model. The presentation of phenomena at the syntactic stage of the cognitive conflict model is displayed in the form of images and videos (Atmam & Mufit, 2023; Mufit et al., 2019; Mufit & Fitri, 2022). The novelty of this research lies in the addition of virtual objects that can be interacted with through touch and movement. IVR design is not only limited to presenting information but also allows students to run quantum physics experiments in a virtual laboratory room. This is in contrast to previous approaches that were limited to two-dimensional quantum physics laboratories (Noer & Mufit, 2023).

The IVR developed obtained valid validation results on aspects of learning, material, and media. These findings are in line with previous researchers who conform to media development standards. Media developed by utilizing technology must obtain valid values on media aspects and material aspects (Samala, Agariadne Dwinggo Dewi & Mursyida, 2023). An attractive display design is one of the most crucial parts of a media development product. IVR met outstanding criteria for visual communication display presentation. Buttons, layout, fonts, colors, arrangement of objects, and feedback that work well are conditions for the product to be used (Arslan et al., 2020). These results were similar to spatial order and the functionality of buttons in the development of IVR as simulation media in the nuclear physics field (Šiđanin et al., 2020).

The developed IVR obtained practical test results in the very practical category. This practical result is in line with previous research that reveals the efficiency and ease of use of technology. The efficiency of the product becomes the main concern in the learning process. Time and cost were essential parts of the assessment and were in the very high category. IVR provides practical and concise learning in understanding concepts (Kugurakova et al., 2021; Patel et al., 2020; Raja & Priya, 2021b). Learning through IVR contributes to time and place efficiency in conducting experimental activities (Chang et al., 2016; Rani & Dwandaru, 2019). Procurement of the number and maintenance of virtual experimental equipment is more effective than actual experimental equipment (Price & Mohr, 2019; Soliman et al., 2021). The product being developed must provide benefits for its users. Augmented, virtual, and mixed reality have been widely implemented in education because they display beauty and effectiveness in conveying information (Gonz, 2020). The results of the benefit indicator assessment are in the high category. IVR was categorized as very practical in understanding concepts, conducting experiments, and assisting independent learning. The use of IVR improves students' performance in studying, helps them process information better, and provides a memorable learning experience (Albus et al., 2021; Nadan et al., 2011). IVR technology allows students to do repeated training (Liu, 2017).

Overall, cognitive conflict-based IVR development results consist of a validity test and a practicality test. IVR prototype has been successfully designed with the presentation of quantum physics material and the stages of the quantum physics learning model. Experts in the valid category's learning, material, and media aspects have validated the prototype design. Based on the efficacy test results, the prototype developed is in the very practical category. Overall, IVR based on the cognitive conflict in quantum physics has been successfully designed with valid and very practical prototype conditions.

## Conclusion & Implications

IVR has been successfully designed by involving elements of cognitive conflict model stages in a virtual environment to explain quantum physics material. Each syntax was presented as a sub-room that merged into a quantum physics laboratory room. The IVR laboratory room contained complete experimental equipment for quantum physics phenomena. The cognitive conflict-based IVR validity test results were in the category of high validity. IVR was valid regarding material substance, learning design, visual communication display, and software utilization. In practicality testing, IVR was very practical in terms of ease of use, display design, efficiency, and benefit. The implications of IVR results support practical learning opportunities in quantum physics.

This research is limited to design, validity, and practicality tests that provide opportunities for researchers to test effectiveness in learning activities. In the future, this research will have implications for interesting and meaningful learning of quantum phenomena according to the characteristics of 21st-century students. Further research can be carried out in a series of experimental studies to determine the effectiveness of cognitive conflict-based IVR products in field tests and on a wider scale. Another limitation of this prototype design is that there is no interaction between students in IVR. Future research development will be to design IVRs using student avatars, which allow interaction between students in learning and experimenting in groups in a virtual environment on distance learning. That is an exciting research challenge and opportunity in the future.

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