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The solution for digitizing traditional practical training models into virtual reality (VR) based virtual practical training models

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ABSTRACT

. Currently, vocational training facilities in Vietnam lack practical equipment, experiments, or have outdated and faulty equipment without sufficient funds for upgrades or new investments to serve vocational skills training due to high costs. In order to partly overcome these difficulties and limitations at current vocational training facilities, the paper focuses on proposing solutions to apply virtual reality (VR) technology in building virtual vocational training models based on traditional skill training practices using equipment and machinery. Then, using digital transformation technologies to construct 3D models of vocational component tools, thereby building virtual vocational training skill practices and testing for metal cutting professions using oxy-fuel flame. With the results of virtual vocational training skill practices, learners will be able to practice repeatedly and be used multiple times, addressing limitations and shortages of practical equipment. At the same time, there are no limitations on space and time as with traditional vocational training equipment. Vocational training facilities will save initial investment costs, and with this virtual practice system, expansion and updates can be easily made without the need for reinvestment as with traditional practical equipment. Additionally, this virtual practice system will innovate teaching methods, practice models, and facilitate faster knowledge transfer to learners, enabling them to absorb knowledge and practice more quickly, mastering the skills of the lesson better.

Key words: Vocational training, virtual reality, training skills, practice model

Introduction

Vocational education plays a crucial role in creating a skilled workforce, generating wealth, and driving the socio-economic development of any country. Vocational education prepares individuals for careers in commerce, craftsmanship, technical fields, or professional occupations such as engineering, accounting, nursing, medicine, architecture, or law. As stipulated in Article 3 of the Unified Document No. 09/VBHN-VPQH dated December 31, 2015, the Vocational Education Law defines vocational education as an educational level within the national education system aimed at providing primary, intermediate, and college-level training as well as other vocational training programs for workers to meet the direct manpower needs in production, business, and services, conducted through both formal and continuing training.

Therefore, the establishment of vocational education is paramount for any country, with a primary focus on educating its citizens to ensure their livelihoods and existence. To ensure the availability of a labor force, each nation must plan, stream vocational education, and invest in vocational education careers. Student streaming is a national education and workforce strategy not only in Vietnam but also in all countries. The history of student streaming education has existed for over 100 years in developed countries, and they continue to improve to meet evolving development needs. While Germany is known for early student streaming, Sweden, the UK, Italy, and Norway have been doing so since the 960s, and France and the US since 1980, and Spain and Portugal since 1990... In Vietnam, the current vocational education program reform demonstrates the correct direction by combining vocational education streaming and elective differentiation, bringing vocational training knowledge to the high school level. This is a positive step, but it requires specific implementation solutions, going into substance, and closely aligning with the interests of learners to gain consensus from stakeholders such as educators, parents, students, and businesses.

Thus, in recent years, Vietnam's political system, state, and ministries/agencies have all focused on education streaming, with a priority policy to promote vocational education. One result is that the number of high school graduates not attending university but opting for vocational education has increased rapidly. This has led to overload in vocational training institutions, where there is a lack of physical facilities, and schools lack practical equipment and laboratories to serve the growing number of students. Additionally, many vocational training institutions lack adequate practical equipment, or if they do, the equipment is outdated. This is a challenging issue in vocational training institutions both domestically and globally.

In Vietnam, as well as worldwide, vocational education has received significant attention from the government, ministries/sectors, and vocational education institutions in recent years. Vocational education has been streamlined and directed right from high school to develop strategies for university education and vocational training. This has addressed the issue of surplus teachers and shortage of skilled workers. However, a prevailing issue in vocational education is that despite substantial attention and investment from the government and ministries in recent years, vocational education institutions under ministries, departments, and vocational training agencies still face many limitations. These limitations include inadequate facilities, equipment, and teaching resources, as well as outdated practical training equipment and tools.

Furthermore, many vocational training institutions have outdated practical training equipment that fails to keep up with trends and lacks the exploration and development of digital transformation technologies, Industry 4.0 technologies, into building modern, virtual, or remote practical solutions to support vocational training institutions. The project "Scientific Research and Development of Information Technology and Communication," KC-01-14 topic by Vu Trong Ry and colleagues, successfully developed software with 20 virtual experiments serving the teaching of Physics 8,9; Chemistry 9; Biology 8,9 [42]. The project "Virtual General Physics Laboratory," conducted by the Institute of Engineering Physics - Hanoi University of Science and Technology, developed virtual physics laboratory software. With liquids, gases, and designed complete equipment and tools, scientific processing and faithful image simulation, experimental operations are simulated "similarly" to reality. Creating virtual practice and experimental environments on computers [36].

To address some of the difficulties and limitations, many researchers, experts, and managers have shown interest in proposing innovative models of practical training and experiments for mechanical, welding, electrical professions, etc., by constructing practical training and experimental models using digital transformation technology. Specifically, in developed countries such as the United States, the United Kingdom, Germany, France, China, South Korea, etc., there has been a particular emphasis on vocational training, with many solutions proposed for applying technology to support practical skills training for learners to enhance their skills and be job-ready upon graduation. These countries have researched and applied the development of products to support smart vocational education practices, integrating advanced technologies into practical training and experiments [1,2]. Many countries have explored the development of applications of virtual reality (VR) and augmented reality (AR) technology in building virtual software, practical training simulations to visually and interactively simulate entire practical training, experimental, and process implementation procedures in virtual space as in real-life situations [3,4]. Based on these virtual practical training simulations, learners practice repeatedly before performing real tasks on equipment.

Thus, this virtual practical training system supports the improvement of the quality of hands-on skill training. In 2021, Scaravetti and François [28] focused on researching the use of AR technology in mechanical engineering. They believe that the application of VR and AR technology will empower learners' learning and autonomy. Moreover, the study also evaluated the relationship between augmented reality and training effectiveness. Some challenges for students when accessing a technical system related to reading and understanding 2D and even 3D representations, lack of knowledge about the functions of components, and analysis of electrical transmission chains and motion conversion have been identified. Research has identified the correlation of AR technology with teaching effectiveness and enhancing access to knowledge for beginners [5,6]. Furthermore, there are research groups applying AR to develop solutions that allow the selection of AR devices and software, enabling an integrated digital chain with tools and digital files used by mechanical engineers [7,8,9] to practice more skilled crafts.

This paper is structured as follows. First, we focus on studying, discussing, and analyzing the current state, advantages, and disadvantages of the application of digital technology and virtual reality (VR) in vocational education and training as researched and published by countries, managers, scientists, and experts worldwide and domestically. Simultaneously, this section analyzes the current limitations and identifies gaps in vocational education institutions in Vietnam in general, and in Thai Nguyen province in particular, as a basis for proposing solutions to implement new technologies such as virtual reality in the digital transformation of vocational skill training practices now and in the future, aiming to innovate teaching methods and improve the quality of vocational skill training. Second, we study, analyze, and propose suitable research methods to be used for digitizing 3D models of tools, instruments, and components related to various professions. From there, these 3D models will be used as a basis for digital transformation and the application of virtual reality (VR) technology to build virtual vocational models. Third, based on research to identify gaps and select research methods, this section of the paper discusses and presents a comprehensive process for constructing virtual vocational skill training practices using VR technology and introduces a specific case study for analysis: the practice of metal cutting with an oxy-fuel gas flame. Fourth, the paper presents specific results of the 3D model digitization used in virtual vocational practices and outlines the detailed steps for constructing the virtual vocational skill practice of cutting metal with an oxy-fuel gas flame. Additionally, the paper presents the results of building the virtual practice and provides comments and evaluations on the quality of the virtual practice from 30 scientists and experts and 250 students currently studying at vocational education institutions. The results show that the virtual vocational practice using VR technology is seen as a solution to overcome the limitations of equipment and machinery shortages in vocational education institutions, contributing to meeting the equipment needs and reducing investment costs for practice equipment and machinery. Particularly, it contributes to innovating teaching methods and improving the quality of virtual vocational training at vocational education institutions.

1 Literature review

VR and AR are significant educational technologies [10], and their application is crucial in developing vocational skills adapting to the technological context engineers need to be trained in. Since 2013, VR and AR have evolved from new technologies into practical teaching tools [11]. In vocational education, applying AR enhances interaction with vocational practice environments [12], allowing for an effective technological platform for training in mechanical engineering [13,14], even for highly precise practical tasks [15], by reducing the mental workload. Tumler and colleagues [16] have shown that working with an optimized AR system can reduce stress compared to traditional practice systems.

For vocational training in fields such as mechanical engineering, electrical engineering, welding, etc., learners often encounter difficulties in mechanics, design, reading technical plans, or 3D models, and in connecting with real systems to determine the dynamic sequence of a mechanism. To address these challenges, Wang et al. [18] evaluated Augmented Reality (AR) in education and training, suggesting that AR technology allows learners immediate access to relevant information for just-in-time learning, providing hands-on training experiences that enable learners to interact with content while immersed in a real environment. Integrating AR into the design of virtual vocational practice sessions will enhance learners' motivation and enjoyment of learning, exploration, experience, and visualization of complex phenomena [17]. Wang et al. [18] and Yuliia et al. (2019) stated that using AR in practical exercises helps learners focus better, increases the sense of "presence," and improves memory retention [19], especially by creating motivational advantages and positive attitudes, enhancing understanding, learning performance, and learner engagement. Milgram and Kishimo [20] discussed the process of creating AR scenarios from CAD data, using Mixed Reality (MR) between tangible interfaces and Virtual Reality (VR), wearable devices (head-mounted displays with gesture recognition), and AR devices to create practical exercises. Scaravetti et al. [21], Dumas [22], advocate for using Augmented Reality as an educational tool, necessitating the application of a technical solution that enables teachers and learners to build skills related to mechanical engineering. Nebeling et al. [23], Imottesjo et al. [24], used CAD technology to represent and display 3D models supporting the construction of detailed parts in practical lectures and describing the detailed operational processes.

Demitriadou et al. [25], Fiorentino et al. [26] argue that in technical training, learners often struggle with mechanical design: reading technical blueprints or 3D models, connecting with real systems, or even determining the kinematic chain of a mechanism. The use of AR technology will facilitate the simulation of mechanical practice exercises. In 2017, MacAllister et al. [27], Washington X. Quevedo [28] used AR to develop a simulation system to identify tools retrieved from a toolbox or to ensure the fit of an assembly (verifying the presence or location of parts). The system comprises an augmented reality environment developed with Unity 3D graphics tools, allowing users to immerse more deeply in the teaching-learning process to optimize materials, infrastructure, and time resources. The proposed system enables users to select the working environment and the level of difficulty in the training process. Experimental results demonstrate the effectiveness of the system created by human-machine interaction aimed at developing practical skills [29,30,31,32,33,34,35].

Therefore, globally, many countries, scientists, and managers are interested in researching and developing applications of new technologies such as VR, AR in constructing and developing simulation software for industrial education in general, and mechanical engineering in particular, which has achieved many successful results and demonstrated the necessity for vocational education institutions in our country, including technical schools, to find solutions to leverage the application of VR, AR technology in designing adaptable, intelligent, remote practical training lessons for students and learners.

The Mimbus group [37,38] specializes in researching solutions applying virtual reality (VR) technology to vocational education and has initially produced products such as: Smart classroom solutions, virtual reality simulation systems, and workforce training support in industries like automotive mechanics, welding, healthcare, with applications designed to provide interactive learning experiences and practical training. The automotive technology training simulation system offers extraordinary hands-on experiences while improving learners' engagement and performance in mechanical training. These applications expand many available opportunities for learners by eliminating consumable materials, reducing training space, and allowing learners to practice in a safe environment [37,38].

The automotive technology theoretical simulation system is the first 3D interactive study guide of its kind designed for automotive training. Learners can interact with customizable courses, run simulations of various automotive systems, and access 3D resources. The system is a theoretical curriculum, a 3D interactive simulation for automotive training, where learners interact with content to enhance their understanding of the detailed structure, overall structure, and operation process of each automotive system and component [39].

The mechanical engineering technical simulation system allows learners to explore mechanical components with 3D simulated objects to develop fundamental principles needed in manufacturing, maintenance, and repair processes [39].

The pneumatic system and equipment simulation system use virtual reality models, dynamic images to help learners understand the detailed structure and connection of pneumatic system components. There are exercises and instructions, tests for building pneumatic systems to provide learners with an understanding of the necessary structure and operation principles of pneumatic systems [40].

The welding practical simulation system simulates welding using the zSpace platform. It allows learners to practice arc welding with exercises ranging from easy to difficult according to European standards. It is the most effective simulated welding machine for learning and practicing welding motion skills. The software allows for the simulation of various welding processes depending on the selected practical lesson. The machine can operate continuously for many hours, comfortable in operation and movement as it is not affected by welding helmets. Compatible with learning management system software, it allows for setting up virtual practice room solutions, consisting of multiple interconnected simulation machines, forming a smart connected class via the network. It can be invested in synchronously or in parts and expanded over time according to the needs and number of learners [41].

The current situation of vocational training in various facilities across Thai Nguyen province, Vietnam, reveals that most vocational training centers still predominantly rely on traditional practical equipment and machinery, with many facing shortages due to the high cost of procurement. Additionally, there is a need for frequent updates and enhancements to meet evolving practical requirements, which can become financially burdensome over time. As of now, none of the vocational education institutions in Thai Nguyen have implemented VR or AR technology to support practical skill training for learners. This represents a significant deficiency and limitation that requires effective investment solutions to transform the vocational skill training model.

The shortage of practical equipment in vocational training institutions nationwide is a common issue. These institutions have yet to fully exploit and catch up with advanced scientific and technological applications, such as virtual reality (VR) and augmented reality (AR), and the outcomes of the fourth industrial revolution. These technologies could be applied to develop smart virtual practical training solutions [37,38,43].

Therefore, the analysis, both globally and in Vietnam, underscores the long-standing focus on researching and proposing solutions for integrating technology into innovative teaching methods and vocational training for practical subjects and experiments. However, many educational institutions still struggle to fully meet current practical training requirements due to various reasons such as insufficient financial resources or a lack of sufficient student enrollment to justify further investment or equipment upgrades. Hence, the search for cost-effective and practical solutions tailored to each vocational education institution is imperative.

This paper focuses on proposing a solution using virtual reality (VR) technology to construct a virtual practical training model and piloting vocational training in metal cutting using oxy-fuel flame.

2 Methodology

One of the crucial tasks in developing practical skill training modules for professions such as mechanics, welding, and electrical work is building 3D models of the tools and components used in these trades. Essentially, this involves converting all traditional practical training equipment and machinery for each trade into computerized format and designing discrete 3D models for each component. These models are then assembled to ensure technical accuracy and adherence to procedures to create a complete practical training module. In this article, the author chooses to focus on metal cutting using oxy-acetylene flame.

3.1. The method of creating 3D models relies on software tools

Figure 1 provides details of some basic 3D shapes. To create 3D models using software tools, the design process starts from the overall structure down to the details: Solid objects are constructed from basic geometric shapes, and 3DS Max software provides a variety of these basic shapes to represent objects in 3D space: spheres, cylinders, boxes, etc. To draw these basic shapes, one can select "Create" from the Command Panel and then choose "Geometry," which will provide a dropdown list of Object Types: Box, Sphere, Cylinder, Torus, Teapot, Cone, Tube, Plane, etc.

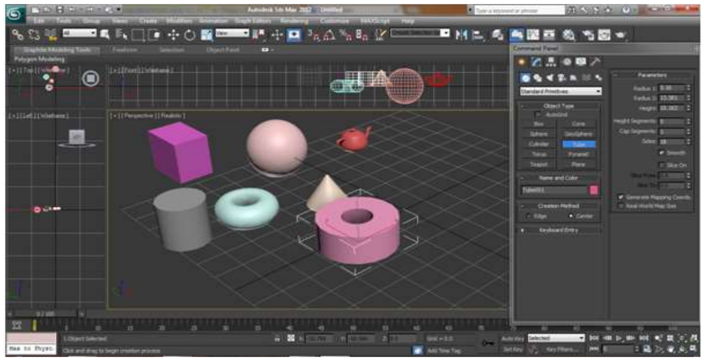


Fig 1. Some basic 3D shapes

(Source: Author's design)

From these basic shapes created above, 3DS Max also provides tools to adjust them to create desired 3D models. There are 3 very useful tools:

Select and Move Tool: Figure 2 provides details about the Select and Move tool in design. Used to select and move objects along the x, y, or z-axis. Once the object is selected, hold the left mouse button and drag the mouse to the new position along the x, y, z axis, or along all three directions. For precise adjustments, you can bring up the Move Transform Type-In dialog by right-clicking directly on the Select and Move button.

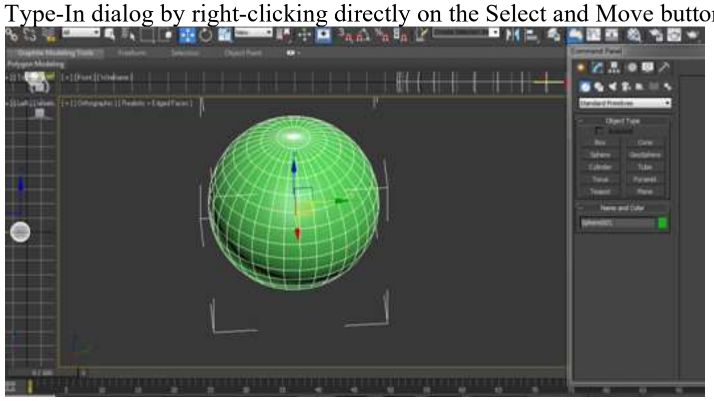


Fig 2. The "Select and Move" tool in design

(Source: Author's design)

Select and Rotate Tool: Used to select and rotate objects, similar to the Select and Move Tool. For precise rotation with high accuracy, you need to bring up the Rotate Transform Type-In dialog by right-clicking directly on the Rotate and Move button and then enter the corresponding values.

Select and Uniform Scale Tool: Used to select and uniformly change the size of objects on the surface or non-uniformly change the size on the surface of the object.

Figure 3 provides details about the advanced editing mode Editable Poly. Advanced adjustment mode Editable Poly: This is the commonly used method for shaping in 3Ds Max. Besides Editable Poly, there are also Editable Mesh, Editable Pactch, NURBS. To use this mode, you need to convert basic shapes into editable shapes. The method is as follows: select the object to be converted, right-click and choose Convert To: -> choose the mode you want to convert to, the Editable Poly mode, the software will display the interface as follows:

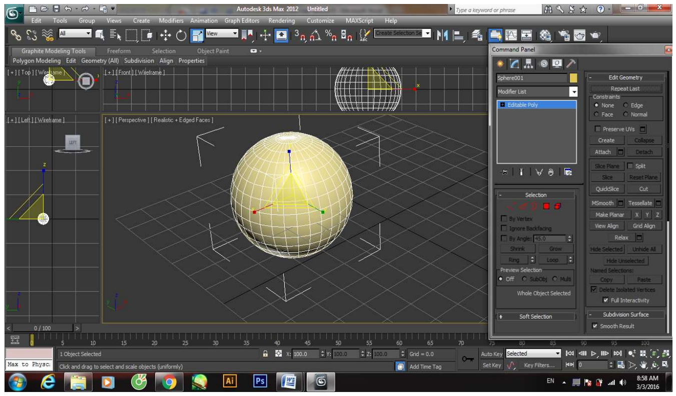


Fig 3. Editable Poly mode

(Source: Author's design)

The adjustment modes include edge, border, vertex, face, and element. Selecting each mode will display a corresponding functional panel. In this way, you can manipulate, pull, and expand to shape the 3D model as desired.

3.2. Method of constructing 3D models based on mathematical models

The method of constructing 3D shapes based on curved surfaces:

Surfaces are constructed by sliding a straight segment along two curves [44]. The surfaces are interpolated linearly from two given boundary curves corresponding to the opposite boundaries of the surface P1(u) và P2(u). Figure 4 provides details on how to construct a surface model.

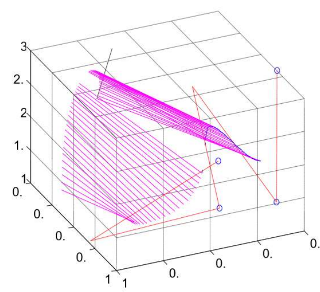


Fig 4. The model of the ruling surface

The equation of the ruling surface: $Q(u,v) = P_2(u)v + P_1(u)(1-v)$

If two given curves correspondingly are $P_1(v)$ and $P_2(v)$

Then the equation of the ruling surface is:

$$Q(u, v) = P_1(v)(1-u) + P_2(v)u = [(1-u)]\begin{bmatrix} P_1(v) \\ P_2(v) \end{bmatrix}$$

The method of constructing a 3D model based on a Revolution surface

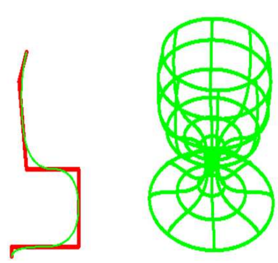


Fig 5. Revolution surface model

Figure 5 provides details on the revolved surface model. The surface is constructed by a straight line or a flat curve around an axis in space. Suppose the flat curve has the form:

P(t)=[x(t) y(t) z(t)] 0≤t≤tmax

Rotating around the x-axis an entity lying on the xy-plane, the surface equation is *Q(t, f) = [x(t) y(t) cosfz(t) sinf]*

$0 \leq \varphi \leq 2\pi$

Illustration of a revolution surface:
P_1[1 1 0] and P_2[6 2 0] lie in the xoy plane. Rotating the line around the ox axis will form a cone. Determine the point on the surface at: t=0.5, f =p/3.
P2[6 2 0] lies in the xy-plane. Rotating the line around the x-axis will result in a cone. Determine the point on the surface at
The parametric equation for the line segment from P1 to P2 is:

$P(t) = [\ x(t)\ y(t)\ z(t)] = P1 + (P1 - P2)\ t \qquad 0 \leq t \leq 1$

With Cartesian components:

$x(t) = x1 + (x2- x1)t = 1+5t$

$y(t) = y1 + (y2- y1)t = 1+t$

$z(t) = z1 + (z2- z1)t = 0$

Using the equation:

$$Q(1/2, p/3) = [\ 1+5t(1+t)\cos f\ (1+t)\sin f\ ]$$

$$= \begin{bmatrix} \frac{7}{2} & \frac{3}{2}\cos\frac{\pi}{3} & \frac{3}{2}\dot{\sin}\frac{\pi}{3} \end{bmatrix}$$

$$= \begin{bmatrix} \frac{7}{2} & \frac{3}{4} & \frac{3\sqrt{3}}{4} \end{bmatrix}$$

The method for constructing 3D models based on swept surfaces ***(Sweep Surface)***

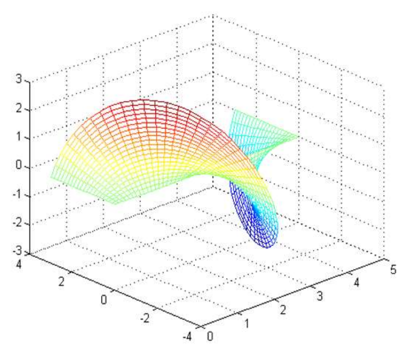


Fig 6. Sweep surface model

Figure 6 provides details on the swept surface model. A sweep surface is a surface generated by sweeping an entity, such as a line, polygon, curve, or shape, along a path in space.

$Q(u, v) = P(u)*[\ T(v)\ ]$

P(u) is the entity to be swept
[T(v)] is the transformation matrix ([T(v)] can be a translation, rotation, or scaling matrix, or a combination of these transformations). For example:

P1[000], P2[03 0]

P(t) = P1 + (P2 – P1) *u = [0 3u01]

$0 \leq u,v \leq 1$

$$|T(v)| = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(2\Pi v) & \sin(2\Pi v) & 0 \\ 0 & -\sin(2\Pi v) & \cos(2\Pi v) & 0 \\ 10v & 0 & 0 & 1 \end{bmatrix}$$

The method for constructing 3D models based on an interpolating surface over four boundary curves (Boolean sum surface): Figure 7 provides details on the Boolean Sum curved surface model. The surface is constructed on 4 points and the boundary curves, S(u,v) is the interpolating surface over the 4 boundary curves.

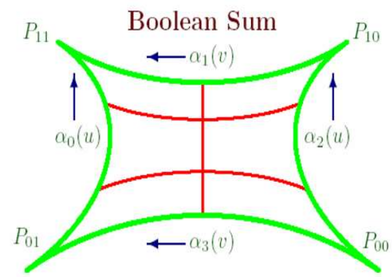


Fig 7. Boolean Sum Surface Model

$S(u, v) = S_1(u, v) + S_2(u, v) - P(u,v)$

Where: $P(u,v) = (1-u)(1-v)P_{00} + (1-u)vP_{01} + u(1-v)P_{10} + uvP_{11}$

$S_1(u,v) = va_0(u) + (1-v)a_2(u)$

$S_2(u,v) = ua_1(v) + (1-u)a_3(v)$;

P represents the vertices of the quadrilateral.

$a_i(u)$ are the boundary curve equations.

Illustration of the Boolean Sum surface:

Where: u = 0

$S(0,v) = S_1(0,v) + S_2(0,v) - P(0, v)$

$= v\, a_0(0) + (1 - v)a_2(0) + 0a_1(v) + 1\, a_3(v) - (1 - v)P_{00} - v\, P_{01}$

$= v\, P_{01} + (1 - v)P_{00} + a3(v) - (1 - v)P_{00} - v\, P_{01}$

$= a_3(v)$

Main findings
4.1 Experimental problem

Vocational education institutions often train students in various fields, each with different groups of subjects, and accordingly, different practical exercises with specific requirements for equipment, machinery, and practice tools. In this paper, the author focuses on proposing the construction of a practical exercise for cutting metal using an oxy-fuel gas flame.

For this practical exercise, the following are required: a welding table, an iron workpiece, a cutting torch head, a cutting torch handle, gas cutting tips, a trigger for the handle, an acetylene gas cutting station consisting of a gas cylinder, a cutting torch, pressure gauges, gas hoses, and other equipment. Additionally, the oxygen cylinder and the fuel gas cylinder must have safety valves and undergo regular inspections.

4.2 Procedure for designing a virtual practical exercise

Based on the actual practical exercise of cutting metal using an oxy-fuel gas flame currently being taught and guided at vocational education institutions, along with the lectures and lesson plans that have been designed to ensure logical and sequential steps of practice. Additionally, using the basic tools and equipment listed in section 3.1 for the practical exercise of cutting metal with an oxy-fuel gas flame. The author presents a schematic diagram describing the process of designing and constructing 3D models of tools and equipment used in the virtual practical exercise for the skill of cutting metal with an oxy-fuel gas flame. Below is the schematic diagram of the design process for constructing the practical exercise using virtual reality technology.

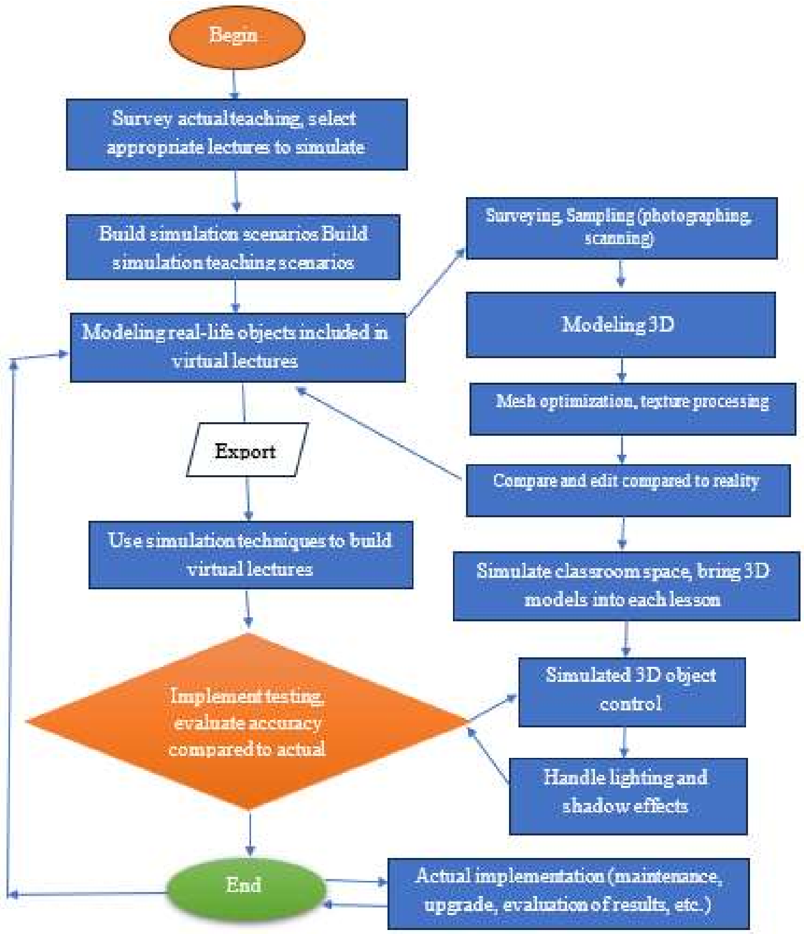


Fig 8. Procedure for designing a virtual practical exercise

(Source: Author's design)

Figure 8 provides details on the virtual practice exercise design process. The schematic diagram above describes each step for designing and constructing a virtual vocational skill training exercise, specifically:

Surveying the actual lectures, practical sessions, and practice equipment and machinery. In this step, tools such as cameras, 3D scanners, and video cameras are used to collect image data of the equipment and machinery.

Developing the teaching script/lesson plan, and creating models of the objects, tools, and instruments used in the practical exercise.

Then, based on the teaching script/lesson plan, constructing the virtual practical exercise on the computer using virtual reality technology by assembling the 3D models with accompanying explanations and practical instructions, ensuring logic and sequential order in the exercise.

4.3. Results of the 3D model of tools and components for the practical exercise

4.3.1. Identification of real tools, equipment, machinery, and apparatus

Figures 9 through 13 provide details on the tools, instruments, equipment, and machinery used in the practical training of students. To enable students to learn the practice of metal cutting with an oxy-fuel torch, the following tools, instruments, equipment, and machinery are required:

Fig 9. Overall dimensions of the welding table frame

Fig 10. Close-up images of the iron workpiece, cutting torch handle, gas cutting tip, and cutting torch head

Fig 11. The acetylene gas cutting station includes a gas cylinder, gas regulator, electrical wires, handle, welding torch, etc.

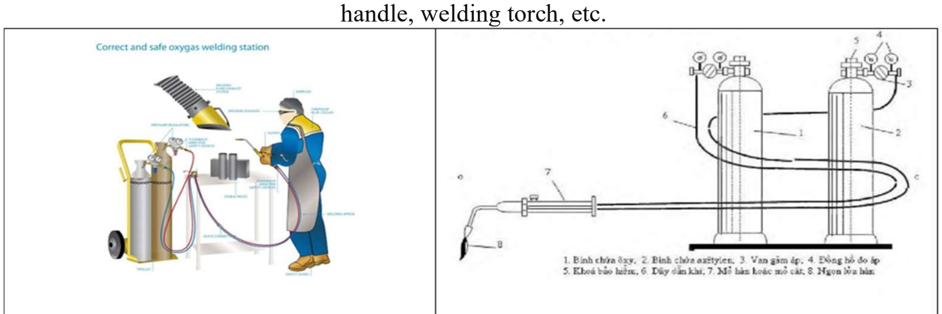
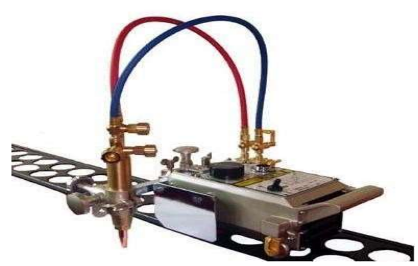


Fig 12. The welding torch handle, gas valve, gas regulator knob, handle, and gas hose.

Fig 13. Image of the HK12 metal cutting machine: includes electrical wires and gas regulator valve



The images of tools, equipment, and machinery collected above will be used to create 3D models.

4.3.2. Construction of 3D models of tools, equipment, and components used in the virtual practical exercise

Based on the images of the tools, equipment, and components used in the practical exercise of cutting metal with an oxy-fuel gas flame, the authors performed the following steps:

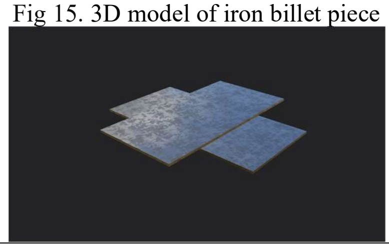
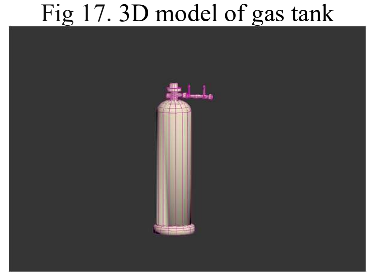
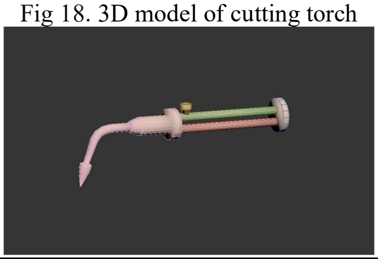
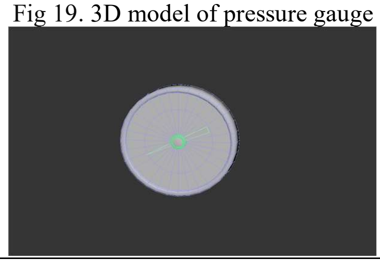
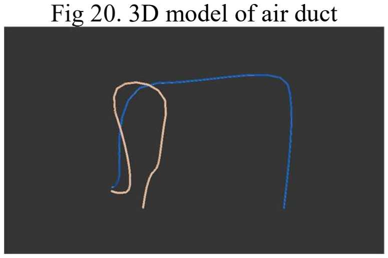
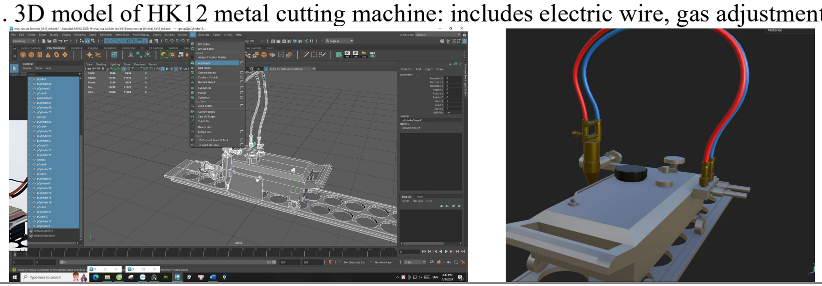
Mapping the actual photographs into graphic software such as Photoshop, 3Ds Max, and Maya 3D to remove noise and fine-tune each component to ensure the actual dimensions of the tools.

Designing and constructing 3D models of the tools, such as the table and the iron workpiece.

Optimizing the mesh and applying textures and materials to the surface of each tool's model.

Analyzing and comparing the resulting 3D models with the actual images of each tool to ensure quality.

Below are some 3D models of tools that were created for use in designing the virtual practical exercise for metal cutting using an oxy-fuel gas flame.

Fig 14. 3D model of table 	Fig 15. 3D model of iron billet piece 
Fig 16. 3D model of air cutting head handle 	Fig 17. 3D model of gas tank 
Fig 18. 3D model of cutting torch 	Fig 19. 3D model of pressure gauge 
Fig 20. 3D model of air duct 	Fig 21. 3D model of gas cutting station using acetylene: including gas tank, gas adjustment valve, welding torch... 
Fig 22. 3D model of HK12 metal cutting machine: includes electric wire, gas adjustment valve 	

Figures 14 through 22 provide details on some 3D models of tools that are built and used in designing virtual practical exercises for oxy-fuel metal cutting. Below are some 3D models of tools that are built and used in designing virtual practical exercises for oxy-fuel metal cutting. With the 3D models of each tool, equipment, and component used in the practical exercise of cutting metal with an oxy-fuel gas flame, the authors will design and construct the virtual practical exercise based on the teaching script and lesson plan. This will be done using virtual reality technology such as Unity 3D and C# programming.

4.4. Results of constructing the practical exercise for cutting metal with an oxy-fuel gas flame

Based on the content of the practical exercise for cutting metal with an oxy-fuel gas flame, the paper outlines the basic steps in a sequential manner to fully construct the practical exercise using software and virtual reality technology as follows:

Step 1 - Preparation: Set up the welding table, iron workpiece, cutting torch head, cutting torch handle, gas cutting tips, trigger for the handle, and the acetylene gas cutting station, which includes the gas cylinder, cutting torch, pressure gauges, gas hoses, and other equipment. Check and install the oxygen and fuel gas cylinders. Ensure that the cylinders have safety valves and undergo regular inspections.

Step 2 - Define the cutting path: This can be done using a template or by marking directly on the metal surface.

Step 3 - Connect and adjust the cylinders: Connect the oxygen and fuel gas cylinders to the cutting equipment. Adjust the pressure and flow rate of the gases during the cutting process.

Step 4 - Initiate oxygen flow: Open the valves of the oxygen and fuel gas cylinders to allow them to flow through the cutting torch and merge at the cutting head.

Step 5 - Ignite the flame: Use an ignition device attached to the cutting torch to ignite the gases and create a blue flame at the cutting area.

Step 6 - Perform the cut: Place the flame at the designated cutting area and move along the pre-defined cutting path.

Step 7 - Cooling process: After the cut is complete, extinguish the flame and allow the metal to cool naturally or use a quick-cooling substance.

Step 8 - Inspect the result: Examine the cut to ensure it meets the requirements of the practical exercise and that there are no undesirable marks.

Results of constructing the virtual practical exercise using virtual reality technology:

Below are some simulation results illustrating the process of conducting the virtual practical exercise for cutting metal with an oxy-fuel gas flame.

Instructions for preparing the tools, equipment, and components needed for the practical exercise; defining the cutting path; and connecting and adjusting the gas cylinders...

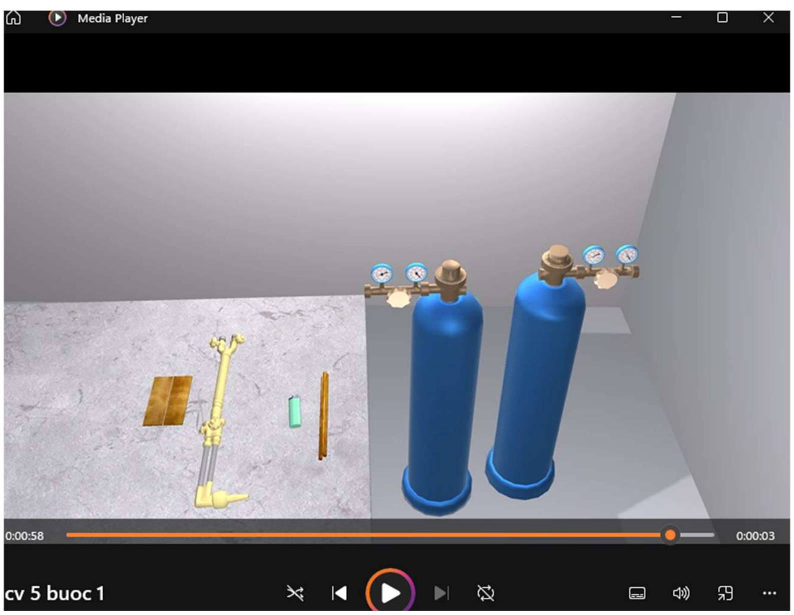


Fig 23. Tools, Equipment, and Components Used in the Practical Exercise

(Source: Author's design)
In the figure 23: a comprehensive introduction of all tools, equipment, and components including the gas cylinder,

regulator valve, pressure gauge, welding torch head, handle, and iron workpiece.
Figures 24 through 26 illustrate the process of oxy-fuel ignition. The oxy-fuel ignition process involves using a lighter to ignite the cutting torch tip.

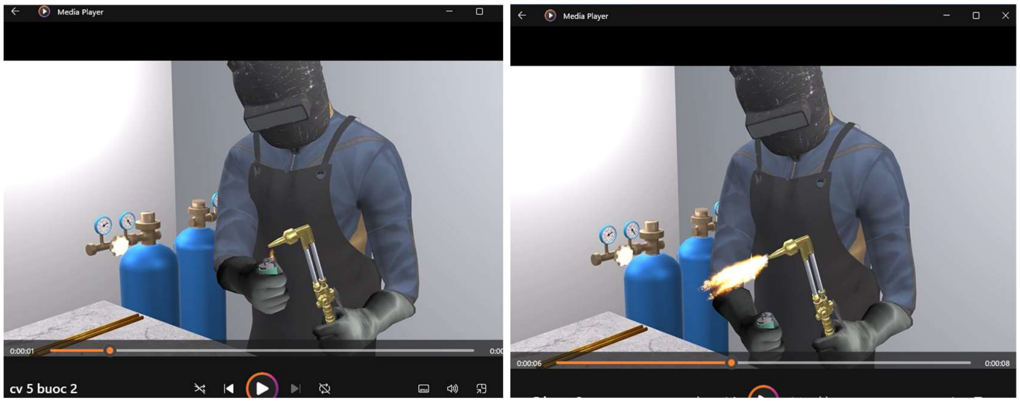


Fig 24. Illustration of initiating the oxygen flow and igniting the flame

(Source: Author's design)

Executing the cutting of the iron workpiece along the predetermined cutting path

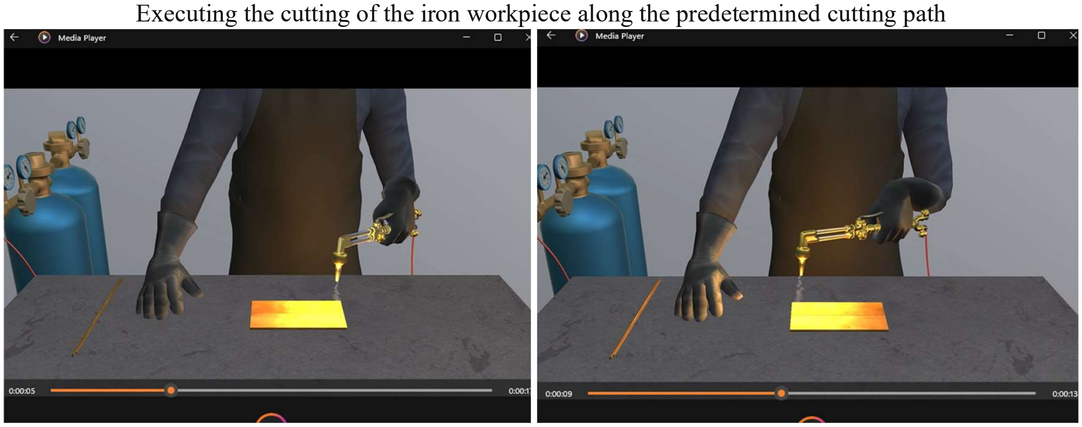


Fig 25. Preheating the iron workpiece before cutting

(Source: Author's design)

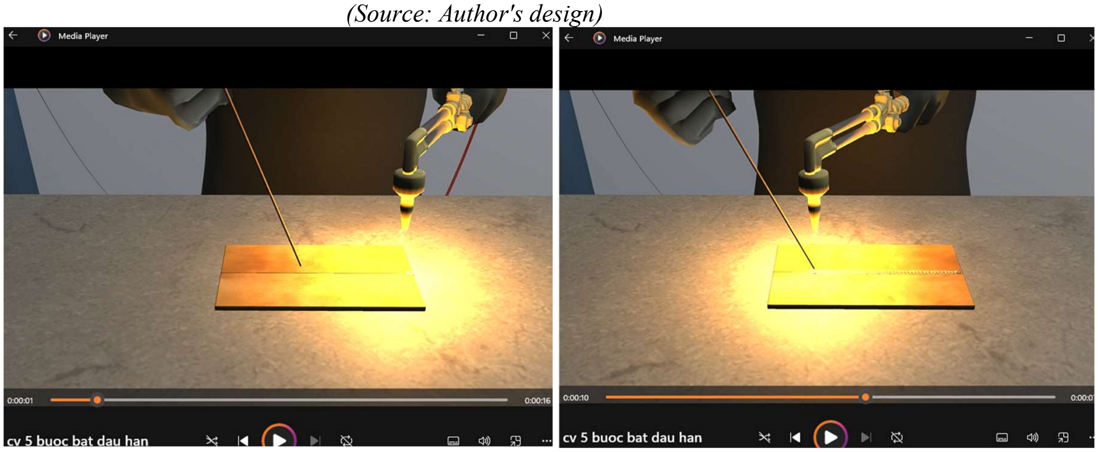


Fig 26. Proceeding with cutting the iron workpiece along the pre-defined cutting path

(Source: Author's design)

The virtual simulation system for the practical exercise of metal cutting using an oxy-fuel gas flame utilizes virtual reality technology to transform from traditional practical exercises. This virtual simulation system is extensively built upon the research content derived from traditional practical exercises. It utilizes multimedia tools such as cameras, scanners, etc., to collect the tools, equipment, and related components used in the practical exercise. Subsequently, 3D models of each tool and component are constructed. Based on this foundation, the system proceeds with designing, arranging, and assembling to construct the virtual practical exercise of cutting metal using an oxy-fuel gas flame.

4.5. Effectiveness of the Virtual Practical Exercise Using Virtual Reality (VR) Technology

To evaluate the quality and convenience of the virtual simulation system for the practical exercise of metal cutting using an oxy-fuel gas flame, the authors conducted an evaluation by organizing a scientific workshop. They invited approximately 30 experts, scientists, and teachers with expertise in welding, electrical engineering, mechanical engineering, etc., along with 250 students from 5 vocational colleges and technical schools in Thai Nguyen province, specializing in electrical engineering, mechanical engineering, welding, etc.

The scientific workshop focused on presenting two main topics: an overview of the content of the traditional practical exercise teaching scenario and a demonstration of the main functions guiding the virtual practical exercise of skill training in metal cutting using an oxy-fuel gas flame in a simulation software environment. The results received evaluations from 30 experts, scientists, educators, and 250 students from 5 vocational colleges and technical schools in Thai Nguyen province. Table 1 presents detailed results of the evaluation of the virtual simulation system for the oxy-fuel metal cutting practical exercise.

Table 1. Evaluation Results of the Virtual Simulation System for Metal Cutting Practice Using Oxy-Fuel Flame

Survey criteria	Experts rated it passable	Experts rated it as unsatisfactory	Learners rated it as passable	The learner rated it as unsatisfactory
About the interface (friendly, easy to use, easy to understand...)	25	5	230	20
Regarding the quality of 3D models of tools, instruments and components used	27	3	235	15
Regarding the practice guide scenario	26	4	220	30
Regarding the accuracy and ease of understanding of the practice instructions	28	2	235	15
Regarding the quality and logic of the voice-over audio that guides the practice lesson	28	2	225	25

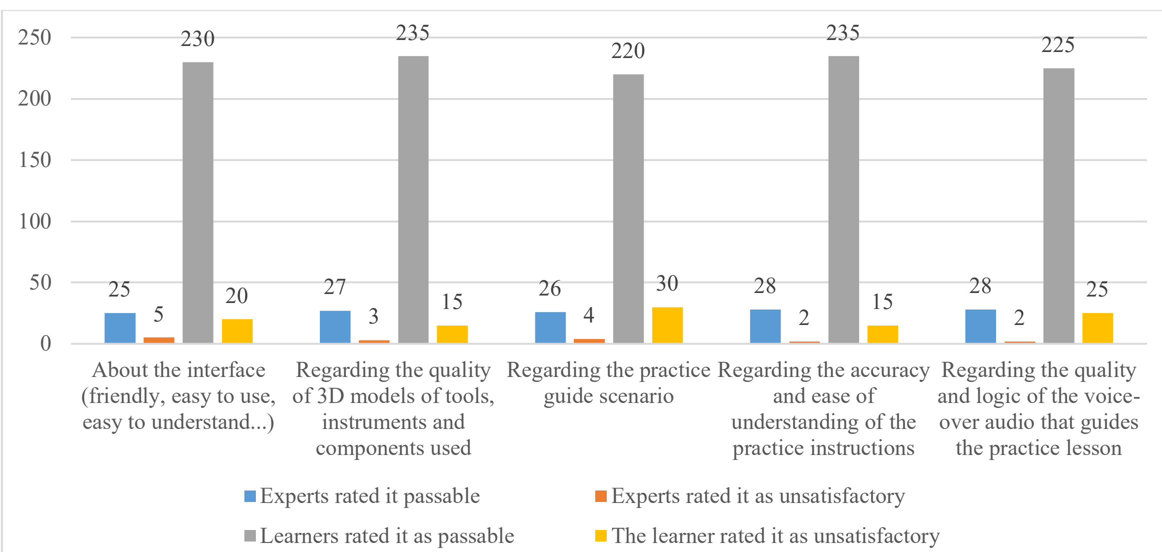


Fig 27. Evaluation chart of the virtual practice simulation system

(Source: Author's design)

Figure 27 illustrates the detailed results of the evaluation of the virtual simulation system for the oxy-fuel metal

cutting practical exercise. Therefore, based on the chart, it shows:
Interface (user-friendly, easy to use, understandable): Up to 83% of experts, scientists, and educators rated the interface as satisfactory; 92% of students evaluated it as meeting the requirements, while the remaining 8% suggested adjustments for friendliness.
Quality of 3D models of tools, equipment, and components used in the practical exercise: 90% of experts, scientists, and educators evaluated the 3D models as satisfactory; 94% of students evaluated the 3D models as satisfactory, while the remaining 6% suggested further adjustments.

Scenario guidance for the practical exercise: 87% of experts, scientists, and educators evaluated the instructional scenario as meeting the requirements; 88% of students evaluated the instructional scenario as meeting the requirements, while the remaining 12% evaluated it as not meeting the requirements.

Accuracy and clarity of the practical exercise instructions: 93% of experts, scientists, and educators evaluated it as meeting the requirements; 94% of students evaluated it as meeting the requirements, while the remaining 6% suggested further adjustments.

Quality and logic of the instructional audio narration for the practical exercise: 93% of experts, scientists, and educators evaluated it as meeting the requirements; 94% of students evaluated it as meeting the requirements, while the remaining 6% evaluated it as not meeting the requirements.

5. Conclusion

In vocational education, practical instruction plays a crucial role and constitutes the main learning content in vocational skill training programs. Through practical exercises using equipment, machinery, or tools, learners can better grasp the lessons and enhance their practical skills. This enables them to enter the workforce immediately after graduation. However, a preliminary survey on vocational training methods, equipment, and machinery at five vocational training institutions in Thai Nguyen province revealed that most schools still rely on traditional methods of practice, mainly using equipment and machinery. However, due to the increasing number of students in vocational education streams, many institutions lack adequate practical equipment and often possess outdated tools and machinery. Consequently, the existing equipment at these institutions only partially meets the practical training needs of the learners.

This article focuses on proposing solutions that leverage digital transformation and virtual reality technology to construct virtual vocational practice models using software platforms such as 3Ds Max, Maya 3D, and programming languages for simulation and control like Unity 3D, C#. The article chose to pilot the construction of a virtual practice lesson for metal cutting using oxy-acetylene flame. The results of the virtual practice exercise were tested with feedback from 30 experts, scholars, and educators currently teaching at vocational training institutions, as well as pilot classes involving 250 students. The evaluation results were synthesized, analyzed, and presented in section 3), indicating that the virtual simulation system for the metal cutting practice using oxy-acetylene flame met the requirements and ensured quality. Through the virtual practice system, learners were able to grasp knowledge and engage in practical exercises more quickly, thereby mastering the practical skills of the lesson more effectively.

6. Data availability

Data generated and analyzed during this study are anonymized and included in this published article. The complete dataset generated during the current study are not publicly available due to data privacy laws

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