Research on Teaching a Welding Implementation Course Assisted by Sustainable Virtual Reality Technology

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Abstract: The purpose of this study is to explore the application of VR (virtual reality) technology to assist the development of VR welding courses in welding practice teaching, and to implement experimental teaching to verify its effectiveness. The preliminary VR welding curriculum structure was developed by this study according to the results of literature review and focus group interviews, the student-based “VR welding course” was developed, and 34 first-year students of the electric welding practice course were taken as the research subjects to implement experimental teaching and case study. The qualitative and quantitative research and analysis results are as follows. (1) The results of the final test of the welding practice of most students are significantly higher than the results of the mid-term test. (2) Most students expressed significant positive affirmation of the learning effect of the VR-assisted welding course. (3) Most students were very significantly positive regarding their learning satisfaction with the VR-assisted welding teaching course. (4) The four major implementation priorities of VR welding courses were planned. This study develops a “teaching mode of a welding implementation course assisted by virtual reality technology”, which can provide students with a safe, low-cost, repeatable, and sustainable welding skills learning environment, and has been positively affirmed by most students. In the future, the results of this study can provide reference for the introduction of virtual-reality-assisted teaching of welding related courses in various universities of science and technology, in order to strengthen teachers’ teaching ability in VR assisted implementation courses and provide students with more diversified learning stimuli.

Keywords: virtual reality (VR); electric welding; education reform; learning effectiveness; learning satisfaction

1. Introduction

With the advent of the era of new digital technology, in addition to bringing more convenience to people’s lives, the requirements of sensory stimulation, such as imagination, interactivity, and immersion, are also becoming higher and higher. Among them, the virtual reality (VR) systems developed by Sony, HTC, Samsung, and other manufacturers in various countries have achieved the most significant results. Moreover, 2016 is considered as the first year of VR, and software and hardware have been actively developed to cater to different types of users since. The 2019 White
Paper report on the Development of the Virtual Reality Industry predicted that China’s VR market size will reach about USD 65 billion by 2023 [1], and that the market size will grow to USD 80 billion by 2025, including USD 45 billion in hardware and USD 35 billion in software [2]. This shows that the application of VR technology in all walks of life is the direction of future development, and it is an urgent issue for educational institutions in various countries to pay attention to.

As the major manufacturers of various countries compete to invest in research and development, with the rapid breakthroughs of science and technology, the cost of VR equipment has been gradually reduced, and the application of VR technology in the field of education has launched a new revolution [3,4]. Many research results show that VR has the media features of sensory immersion, navigation, and maneuverability. In learning, VR can provide direct experience that enables students to experience the environment and the actual implementation, and can also act as a promoter of positive emotions to create effective and better learning outcomes [5,6]. Therefore, VR technology, which provides immersive learning with remarkable results, has been widely applied in engineering education and skills training, and also conforms to the connotation of learning theories, such as constructivism, experiential learning, and situational learning; for example, Abulrub and Attridge [7] applied VR to engineering training and education, and Kriz and Prochaska [8] applied VR to nuclear power plant safety education and training, which can guide learners in an interactive and exploratory manner without being restricted by the actual environment, and assist learners to understand course knowledge and improve their practical abilities. It has been shown that the application of VR technology in engineering-related practical teaching can strengthen the students’ immersive sense of integration and interaction characteristics and reduce the learning time [9]. In addition, it can provide students with opportunities for repeated practice, which increases the effects of skill proficiency without increasing the cost of additional consumables and provides a safe learning field [10].

Therefore, as a teaching aid for various skills verification courses, if VR technology can be applied in vocational and technical education, it will transform practical experience into usable knowledge and skills through virtual situations and thus play an active role in the learning environment of VR systems to realize real learning [11,12]. According to the 2019 Labor Statistics Report [13], the item with the lowest qualification rate of Grade C skill verification is the welding piping group, which indicates that the effectiveness of current welding training courses is lower than that of other kinds of skill verification training courses; thus, it is necessary to introduce VR technology to assist teaching.

With the rapid growth of the global economy and the improvements of industrial technology, welding technology is used to process and repair metal products, such as automobiles, machinery, shipbuilding, spacecraft, nuclear reactors, household appliances, construction, etc. [1,14]. According to the data of the National Institute for Occupational Safety and Health (NIOSH), the labor population engaged in electric welding in industrialized countries is estimated to be about 0.2–2% of the total labor population [15], which shows that the cultivation of welding technology skilled workers is worthy of attention.

According to statistics from the Skill Evaluation Center of Workforce Development Agency, Ministry of Labor in Taiwan [16], there are more than 1000 people applying for a general manual welding practitioner certification every year, with an upward trend year by year, and the number of applicants in 2019 exceeded 1600. Nevertheless, due to the ability-oriented demands for welding manpower, the inspection qualification rate in 2019 was a record low at only 58.3%, resulting in a serious shortage of skilled welding workers in the industry and the dilemma of short supply.

Going back to the roots, the fundamental solution lies in the reform and practice of welding worker training and education. According to a review of the traditional welding technical personnel training models, which feature high monetary costs, long cycle equipment, high manpower requirements, extensive raw materials, and high energy costs [17], such courses consume a large amount of welding rods and workpiece materials and produce toxic and harmful gases, dust, ultraviolet rays, radiation, and electromagnetic pollution to cause certain harm to the students’ health [18]. Therefore, actively considering and improving technical and vocational education is a worthy topic in order to teach engineering educational units how to apply emerging technologies to welding personnel.
training, improve the learning effectiveness of the students’ welding knowledge, reduce the input cost of welding training, reduce the physical hazards caused by the welding training process, and provide real practice and safe experience [19].

In view of the abovementioned, this study explored the course design of electric welding practice with VR technology in the universities of science and technology, developed VR electric welding course units, and explored the impact of VR-technology-assisted electric welding practice teaching on students’ professional welding ability. It is intended that this course can strengthen students’ welding knowledge and skills learning effectiveness.

2. Literature Review

2.1. Development and Application of Welding Technology

Welding is a technique in which two or more metal weldments are heated to an appropriate temperature at the place to be joined, welding rods are added, and pressure is applied, and after they are condensed, they are combined into one body, meaning that the atoms are combined to form a permanent connection [20]. Common welding methods include gas welding, resistance welding, arc welding, laser welding, and e-beam welding. There are currently more than 100 laser welding production lines in the global automotive industry, including BMW, Volkswagen, General Motors, Toyota, and other automobile assembly production lines. In addition, under Taiwan’s policy of the active promotion of the offshore wind power industry, 104 corporations pointed out that Taiwan began to have offshore wind power job vacancies in 2016, and this number increased sharply in 2019. The number of job vacancies that require welding abilities was 103 more than in 2017, with a growth rate as high as 3.6 times. Moreover, numerous welding engineering, mechanical, and electrical engineering projects require welding abilities for the maintenance of equipment, which is important during the initial construction of projects [21].

2.2. Electric Welding Technology Training

The quality of welding technology directly determines the quality of its products and construction quality [22]. Therefore, the professional technical threshold for electric welding requires personnel to learn basic electric welding knowledge and skills from schools or vocational training units, including the use of equipment commonly used in electric welding, such as the argon welding machine, electric welding machine, welding gun, welding rod, grounding clamp, and other operations, as well as the use of hand tools and slag removal tools, such as steel brushes, slag hammers, etc. Furthermore, welding personnel must be able to identify material characteristics, select suitable welding methods, fillers, and welding rods, perform metal processing procedures based on the construction drawings, inspect the weld bead to visually check whether the weld bead has defects, such as penetration welding, welding corrosion, insufficient penetration, and cracks, and perform mechanical inspections (e.g., X-ray irradiation, ultrasonic inspections, etc.) as per customer requirements. Therefore, in order to be engaged in welding work, one must be familiar with welding structure drawings, symbols, various welding machine performance and device methods, as well as the characteristics of various special ferrous and non-ferrous materials, and the selection of welding rods/welding wires/fillers. It is also necessary to have welding metallurgical knowledge and understand how to prevent weldment deformation, preheating/post-heating, and other treatment methods.

In recent years, the exposure hazards of welding workers have become important topics of labor safety and health research in advanced industrial countries [23]. In the welding environment, attention must be paid to whether there are flammable materials or volatile gases, and good ventilation equipment is required to avoid humid or conductive working environments. Personal protection includes safety helmets, breathing protection equipment, safety belts, safety shoes, safety gloves, protective clothing, and other protective equipment [24,25]. Finally, the students are trained to acquire the basic welding skills and related knowledge, and have focused, diligent, and responsible service
spirit, as well as the professional ethics of work commitment and teamwork, in order that they can safely engage in electric welding related operations after training.

2.3. VR Technology Development

VR refers to the use of computer-related software and hardware technology to create a three-dimensional virtual scene, where visual, auditory, and other sensory simulations are provided to allow users to have an immersive experience, which can achieve an immersive effect and increase the user’s perception experience [26,27]. Successful VR offers a multi-sensory experience that allows users to have a virtual scene as if in the real world and makes users feel the lifelike and vivid images via VR interface devices and interaction with the scene; thus, it should have the three important characteristics of interactivity, integration, and imagination [28].

2.3.1. Interactivity

The presentation of simulated scenes allows users to interact with the objects in the virtual scene, and to obtain real-time, dynamic, and interactive responses through various input devices, such as head-mounted displays, data gloves, position trackers, etc. It is pointed out that highly interactive VR can increase learners’ interest in learning and the applicability of VR [29,30].

2.3.2. Integration

Computer-related software and hardware technology is able to integrate users into the 3D VR generated scene in order that users can have various sensory feelings and immerse themselves in the virtual world, which is controlled by the user; when VR is used in teaching, the higher the user’s immersion in the virtual environment, the higher the learning effectiveness [31].

2.3.3. Imagination

The creation of VR can provide users with imagination. Through the virtual images, sounds, and light effects generated by computers, users can imagine putting themselves in the virtual space to enhance their willingness to use and learning interest [32].

As VR has the abovementioned features, it produces positive effects in educational applications, especially in the designs of “immersion”, “real-time feedback”, “thematic tasks”, and “high cognitive tasks”, which can increase the degree of interaction between users and digital content, and finally, can create more effective and better learning effectiveness in teaching [33]. Especially in situations where skills acquisition is costly, infeasible, or too dangerous in reality, VR technology can provide realistic simulation and the possibility of virtual exploration [34,35]. Therefore, the proportion of VR technology in teaching applications is increasing year by year [36].

Based on the above, VR technology can provide interactive realistic scenes, which can be applied to teaching, and students can repeat the correct welding posture exercises under safe and secure conditions. Therefore, this study applied VR technology to the practical welding course to help students train and absorb the knowledge of welding. This course used a desktop VR equipment-guide WELD VR welding simulator and matched VR Box, 3D stereo glasses, and other VR products to increase the richness of the VR course and help students learn.

2.4. Application of VR in Engineering Education

VR technology is the current trend in the application of teaching technology. Freina and Ott [37] pointed out that, while computer science and engineering are the majority, VR can be used in computer science, engineering, mathematics, social sciences, medicine, physics, and other subjects. Coupled with the drop in the price of hardware and software VR equipment, as well as the lowered threshold for operation technology, the feasibility of VR being used in education has been improved [38]. The main feature of VR technology is that the learning or training environment and feelings can be reproduced
regardless of location and time, which not only improves the limitations of traditional learning methods, it also enhances the communication of educational training content and information through the interactive and realistic characteristics of VR [39].

Research regarding the application of VR to education has revealed the three main characteristics of VR, namely, integration, interactivity, and imagination. Learners can interact with virtual scenes through VR interface devices during the learning process [28], which serves as a teaching tool for implementing more abstract or practical course content [40,41]. The application of VR technology to engineering education can provide opportunities for trial and error, improve students’ participation, and ensure that students are better prepared for their future careers [42]. In addition, Abulrub and Attridge [7] planned VR course experiments related to engineering education to offer experiential learning and provide students with the opportunity to explore the actual technology, which can increase course participation, improve student interaction, and enhance students’ learning motivation and attitude. Teachers believe that VR can be used as an effective teaching aid, as the equipment is easy to master, and the teaching materials are correct; thus, students’ understanding of and concentration in the course are improved.

This study believes that the application of VR in auxiliary teaching has become a trend. Many research results also show that VR technology can attract students’ attention and stimulate their learning motivation in the teaching application [43,44]. In addition, as VR is positive for learning, it will have greater development space in the future [45,46]. However, simply introducing information technology into teaching does not guarantee the improvement of students’ learning motivation and effectiveness [47]; thus, how to effectively introduce the advantages of information technology into course content and activities and design learner-centered courses to improve students’ learning effectiveness is worthy of further study [48].

To sum up, this study made good use of the characteristics of VR when planning VR application to welding practice courses to help students immerse themselves in the welding scene in teaching, which is conducive to students’ repeated learning of welding skills and stability; improves students’ concentration, understanding, and participation; and allows students to actively explore the curriculum and have opportunities for trial and error in practice [49].

3. Research Design

This study aimed to improve and deepen the teaching aids and cross-field textbooks of the “Electric Welding Practice Course”, develop the VR electric welding course, and discuss its implementation effects. The relevant research design and implementation are described, as follows.

3.1. Research Structure

The research structure of this study was formed according to the research purpose and related literature review, as shown in Figure 1. This study adopted the case study design with multiple evaluation methods, including welding practice tests, questionnaires, study sheets, and qualitative interviews to explore the impact of the integrated teaching method of VR on the learning effectiveness and learning satisfaction with the mid-term and final exams of the welding practice courses of the engineering students of the universities of science and technology.

![Figure 1. Research flow chart.](image-url)
3.2. Research Method

This study adopted the case study method to study a unique object and establish the research theme (constructing theory), then observed and recorded the facts (collecting data), asked questions (analyzing data), proposed solutions, and finally, established decisions [50]. Therefore, this study conducted a VR welding practice course and collected extensive qualitative and quantitative data to analyze and summarize the effects of “VR technology-assisted welding practice teaching” on the students’ electric welding learning effectiveness, which can be used as a reference for future improvements of teaching electric welding courses.

3.3. Research Subjects

According to the purpose of this study, the subjects were 34 students taking the first-year electric welding practice course of the case university of science and technology. This study implemented an 18-week VR electric welding course, carried out questionnaire surveys and text data collection, and conducted statistical analysis to discuss the students’ performance of welding practice tests, learning effectiveness, and learning satisfaction with the welding course.

3.4. Research Tools

This study was based on literature review to summarize welding course teaching and the focus of VR applications in engineering and teaching, and developed research tools, including the VR welding course materials, the VR welding system and equipment, student study sheets, student questionnaires, etc. The content of the self-edited student questionnaire includes three parts: introduction to the instructions of answering the questionnaire, basic data of the respondent, and the questionnaire questions. Among them, the questions are the focus of this research, including the two major constructs of learning effectiveness and learning satisfaction, for a total of nine questions, as shown in Table 1. Single sample t verification analysis was adopted. In addition, student study sheets and interview outlines were developed and supplemented by the qualitative analysis results to explore the learning status of students in the VR-assisted welding courses.

| Item                              | Quantitative Analysis | Qualitative Analysis |
|-----------------------------------|-----------------------|----------------------|
| Welding practice test             | Significantly positive| Students have the skills to apply electric welding and the ability to solve problems |
| Master the learning progress      | Significantly positive| VR-assisted teaching allows students to understand their own learning progress |
| Improve learning efficiency       | Significantly positive| Integrated VR welding practice improves learning efficiency |
| Strengthen welding skills         | Significantly positive| VR-assisted teaching strengthens students’ welding skills |
| Enhance learning interest         | Significantly positive| Integrated VR welding practice training increases learning interest |
| Improve learning safety           | Significantly positive| VR-assisted teaching improves the safety of students in the field of welding practice |
| Reduce learning pollution         | Significantly positive| VR-assisted teaching can be repeated many times to reduce pollution sources |
| Lower learning costs              | Significantly positive| VR-assisted teaching can be repeated many times to reduce learning costs |
| Increase evaluation of learning effectiveness | Significantly positive | Diversified display of student learning effectiveness |
| Strengthen traditional welding teaching | Significantly positive | Integrated VR welding practice teaching can assist traditional welding teaching |
This study refers to the triangulation method, as proposed by Denzin in 1978, and adopts a variety of data collection methods to test the consistency of the research findings [51]. From the perspective of interviews with students, observations of learning processes, and feedback from students’ learning sheets, this paper analyzes the feedback from students and further explores the factors that may affect students’ learning performance. The text data is coded according to student groups; for example: S0203; the first code “S” represents the student, the second and third codes “02” represent group 2, and the fourth and fifth codes “03” represent the feedback from the third student in that group.

In addition, the welding test includes two kinds of questions: flat welding and fillet welding, which are scored by teachers and welding teaching assistants. The average value is taken to evaluate the students’ actual performance of welding ability before and after the VR-assisted welding teaching, with a total score of 100.

3.5. Validity and Reliability

Content validity was used to validate the research tools of the questionnaire survey. The first draft of the questionnaire was constructed according to the literature review of relevant theories and researches, interviews were conducted with three experts with rich experience in electric welding and VR applications to obtain the correction opinions, and then, the questionnaire was revised and designed accordingly. Therefore, this questionnaire has sufficient expert content validity. In addition, in terms of the reliability of the student questionnaire, the Cronbach’s $\alpha$ value of the overall construct reliability is 0.739, and the test results of the various constructs are 0.752 for learning effectiveness and 0.721 for learning satisfaction. Regarding reliability analysis, Cronbach’s $\alpha$ values are all greater than 0.7, indicating that the questionnaire in this study has high reliability.

3.6. Research Limitations

The subjects of this study are 34 freshmen in the University of Science and Technology. The experimental subjects (samples) are mainly the students of the Engineering Department, and the number of students participating in the welding implementation course was slightly insufficient, which is the limitation of this study.

3.7. Curriculum Design and Teaching

This study used Unity software and “guide WELD VR” welding teaching equipment to develop a virtual and reality integrated welding practice course suitable for universities of science and technology. According to the ability indicators of this welding course, this study designed the course content, including the ability to read and make drawings, operation preparation, sample processing and combination, welding operation, welding bead cleaning, welding inspection, and industrial safety and hygiene practices, gain the professional ethics of electric welders, understand the curriculum content, and apply the integrated VR teaching activities, as described below.

The curriculum design of the “VR Welding Course” in this study is “student-centered”, as shown in Table 2. By referring to the importance of the ability indicators of the electric welding course, the traditional 18-week electric welding practice course content was adjusted in proportion to improve students’ welding ability. Furthermore, based on the feasibility of VR-assisted welding teaching, VR technology was integrated and applied to welding course units, thus providing students with diversified welding learning stimulation and auxiliary teaching activities. Course contents include site preparation per week, the basic welding knowledge units in the 1st–2nd weeks (including familiarization with the welding operating environment, learning welding procedures, and practicing welding operation posture, speed, and related safety and health precautions), the basic welding practice units in the 3rd–4th weeks (including the welding arc length, the angle between the base metal and the welding rod, and the welding speed), the advanced electric welding practice units in the 5th–8th weeks, and the electric welding special application units in the 10th–17th weeks, as well as the items of the mid-assessment in the 9th week and the final assessment in the 18th week. During course
implementation, VR welding equipment simulation teaching was used according to the unit attributes of each week, including VR-assisted welding operation safety simulation, VR-assisted welding skills and stability, VR-assisted simulation of welding test, and VR-assisted welding remedial teaching, in order to enable students to lay the foundation for welding professional skills.

| Week              | Course Outline                                                                 | VR Assisted Teaching                                                                 |
|-------------------|--------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Weekly            | Site preparation, including: turn off the power of the machine, maintain and return tools, clean up the workbench, remove waste, clean the environment, use the equipment carefully, and cherish public property | VR understanding of the welding factory environment and equipment layout to establish students’ safety and health recognition concepts. |
|                   | 1. Brief introduction of AC welding machines, functions and comparison of AC welding machines |                                                                                     |
|                   | 2. Brief introduction of CNS mild steel electrode numbering principles, and the application of mild steel electrodes | VR welding equipment operation teaching and welding operation safety simulations to provide students with learning opportunities. |
|                   | 3. Introduction of the selection of personal appliances and safety lenses for welding operations |                                                                                     |
|                   | 4. Explanation of the safety rules of electric welding operation and introduction of equipment relevant to a welding workshop |                                                                                     |
|                   | 1. Protective equipment, welding posture (including electrode chuck holding method, electrode holding method) | VR-assisted welding skills and basic posture stability teaching, linking students’ prior knowledge of electric welding for proficiency in electric welding methods. |
|                   | 2. Electric welding machine operation, current adjustment, arc initiation method, and flat weld straight line welding |                                                                                     |
|                   | 3. Electric welding arc damage and protective measures, electric shock hazard and prevention methods |                                                                                     |
|                   | 4. Demonstration, explanation, and practice |                                                                                     |
|                   | 1. Proper welding arc length |                                                                                     |
|                   | 2. The angle that the base metal and the welding rod should maintain during welding |                                                                                     |
|                   | 3. The welding points of flat welding, horizontal welding, vertical welding, and overhead welding |                                                                                     |
|                   | 4. Demonstration, explanation, and practice |                                                                                     |
| The 3rd to 4th weeks | Mid-term exam: 1. Finished product review, joint evaluation by teachers and students | VR-assisted advanced teaching of welding skills and weld stability to strengthen students’ welding methods, and ensure that students acquire practical welding skills. |
|                   | 2. Answering students’ questions and summarizing the key points of this course | VR simulation welding test, in order that teachers and students can understand the learning effectiveness of welding knowledge and skills. |
|                   | 2. Prevention and improvement methods of weld bead defects |                                                                                     |
| The 5th to 8th week | Operation practice: (Teachers give individual guidance to correct students’ welding posture) 1. Strengthening the welding exercises demonstrated by the teacher | VR-assisted welding practice, remedial teaching and VR simulation welding test to correct students’ misconceptions, and ensure that students’ welding skills can be widely applied. |
|                   | 2. Completing the assignments on the work order |                                                                                     |
|                   | Final exam: 1. Finished-product review, joint evaluation by teachers and students | VR simulation welding test, in order that teachers and students can understand the learning effectiveness and application results of welding knowledge and skills. |
|                   | 2. Answering students’ questions and summarizing the key points of this course |                                                                                     |
| The 9th week      |                                                                                   |                                                                                     |
| The 10th to 17th weeks |                                                                                   |                                                                                     |
| The 18th week     |                                                                                   |                                                                                     |
In terms of teaching activities assisted by VR technology, this study planned the use of “guide WELD VR”, which is a VR welding teaching equipment system, to assist in teaching the welding practice course. The types of welding methods in this system are GMAW (gas metal arc welding) and SMAW (shielded metal arc welding). Related hardware devices include desktop screens and projection screens, CO₂ welding (GMAW/MIG) simulation welding guns, metal coated arc welding (SMAW/STICK) simulation welding guns, molds for three welding methods: butt, overlap, T-joint, and other molds, simulation welding platform, etc. This system software has built-in welding examples, and supports teachers to create example courses, where they can set materials (steel, stainless steel, aluminum), working angle, travel angle, direction, speed, and other parameters, including practice mode and test mode. Among them, there are prompt instructions in the practice mode, including distance, work angle, travel angle, direction, speed, etc. The test mode has a built-in scoring system can help teachers understand students’ learning status and make technical assessments. The relevant operation steps are described, as shown in Figure 2, as follows:

**Figure 2. Operation steps.**

Step 1: Select the welding method and mode.

Step 2: Set the welding bead of the system.

Step 3: Welding torch angle prompt.

Step 4: Nozzle plate (distance between welding torch and workpiece).

Step 5: Prompt for welding torch travelling speed.

Step 6: Feedback of simulated welding data.

Step 1: Select the welding method and mode, which is the practice mode of CO₂ welding (MIG) and T-joint. The system records personalized learning data, and learners can enter their personal accounts to build a personalized learning database.
Step 2: Set the welding bead of the system, on both sides of the T-mold to determine the path of the welding bead.

Step 3: Welding torch angle prompt. In the VR screen of the practice mode, there is a welding torch angle prompt symbol, which includes working angle and travelling angle, to assist learners to develop the correct welding posture and practical operation. The working angle prompt (the downward arrow at the top left) indicates that the pitch angle of the welding torch must be tilted toward the operator; on the contrary, if there is an up arrow, the pitch angle of the welding torch must be tilted towards the workpiece. The travelling angle prompt (the right arrow at the top right) indicates that the left and right angles of the welding torch should be tilted to the right; if there is a left arrow, the reverse is true.

Step 4: Nozzle plate (distance between welding torch and workpiece) prompt. In the VR screen of the practice mode, there will be a green prompt light at the front of the virtual welding torch to assist learners in learning to maintain the stability of the optimal distance between the welding torch and the workpiece. The green prompt light indicates the optimal distance between the welding torch and the workpiece, and when the distance between the welding torch and the workpiece is too far or too close, there will be a red prompt light to remind learners to adjust.

Step 5: Prompt for welding torch travelling speed. In the VR screen of the practice mode, there will be various symbols, such as “=”, “+”, and “-”, wherein, “=” means that the current travelling speed of the welding torch is optimized, “+” means that the travelling speed of the welding torch is too slow and must be increased, and “-” means that the travelling speed of the welding torch is too fast and must be slowed down. In this way, the learners are assisted to develop a stable travelling speed of the welding torch, in order to improve the quality of their welding.

Step 6: Feedback of simulated welding data. In the practice and test modes, the VR welding system will provide personalized feedback of the simulated welding data, including working angle, travelling angle, nozzle plate position, travelling speed, straightness, and test scores. In addition, the system provides videos and the historical data of students’ welding status for playback, observation, and review, and teachers and learners can understand the current welding learning status as a basis for further learning or remedial teaching.

4. Results and Analysis

According to the purpose of this study and the literature review, the “VR Welding Course” for the engineering students of universities of science and technology was developed, and experimental teaching was implemented. The mid-term and final tests of the welding practices, the questionnaire survey, and the study sheets were implemented during the course, and the results of qualitative and quantitative analyses are as follows.

4.1. Analysis of Student Welding Practice Tests

In order to understand the impact of the VR welding course on the students’ welding practice skills, the 18-week VR integrated welding practice course planned to implement the welding practice mid-term test in the 9th week and the electric welding practice final test in the 18th week, and the teachers and teaching assistants scored the welding practice works of the 34 students, respectively. After the average value was taken, paired sample t-test statistical analysis was carried out, as shown in Table 3. According to the results, the average of the 34 students’ pre-test scores is 82.824 (SD = 1.783), the average of the post-test scores is 85.618 (SD = 0.739), and the t value is −8.489 (DF = 33; p-value = 0.000 < 0.05), reaching significant positive difference. This result shows that the final test evaluation of the performances of the welding practice works of most students after VR integrated welding practice course teaching are generally higher than that of the mid-term test.
### Table 3. Analysis of students’ welding practice pre-test and post-test statistics (n = 34).

| Category     | Mean    | Standard Deviation | t    | Df | p-Value |
|--------------|---------|--------------------|------|----|---------|
| pre-test     | 82.824  | 1.783              | −8.489 | 33 | 0.000   |
| post-test    | 85.618  | 0.739              |       |    |         |

#### 4.2. Analysis of Students’ Learning Effect of VR Welding Course

After 18 weeks of the VR integrated electric welding practice course, the 34 students completed the questionnaire of “learning effectiveness” and “satisfaction” in order to understand the impact of the VR welding course on students. The results of the questionnaire survey were based on single sample t test analysis, as shown in Table 4, which are described as follows.

### Table 4. Analysis of student learning effectiveness and satisfaction.

| Construct          | Item                                                                 | Average Mean | Standard Deviation | t    | Verification value |
|--------------------|----------------------------------------------------------------------|--------------|--------------------|------|--------------------|
| Learning           | (1) VR-assisted welding teaching allows me to master the learning process more accurately | 4.03         | 0.85               | 7.41 *** | 3; *** p-value < 0.000 |
| effectiveness      | (2) VR-assisted welding teaching makes my learning more efficient     | 4.05         | 0.87               | 7.47 *** |                     |
|                    | (3) VR-assisted welding teaching made me get used to welding muscle memory | 3.95         | 0.87               | 6.73 *** |                     |
|                    | (4) The immersion of VR-assisted welding teaching can stimulate my interest in learning | 3.92         | 0.85               | 6.68 *** |                     |
|                    | (1) VR-assisted welding teaching can improve the personal safety of welding training | 4.08         | 0.97               | 6.86 *** |                     |
|                    | (2) VR-assisted electric welding teaching has low pollution and is very environmentally friendly | 4.08         | 0.91               | 7.29 *** |                     |
|                    | (3) VR-assisted welding teaching saves costs                          | 4.05         | 0.87               | 7.47 *** |                     |
|                    | (4) VR-assisted welding teaching makes it easier to evaluate students’ welding skills | 4.00         | 0.84               | 7.35 *** |                     |
|                    | (5) VR-assisted welding teaching can strengthen traditional welding training | 3.95         | 0.80               | 7.27 *** |                     |

In terms of learning effectiveness, the scores of the four questions ranged from 3.92 to 4.05, which all reach significant difference, indicating that most students expressed positive affirmation for the learning effectiveness of VR-assisted welding teaching. Among them, item 2, “VR-assisted welding teaching can shorten the learning time and be more efficient”, received the highest score of 4.05 with the t value of 7.47; followed by item 4, “VR-assisted welding teaching allows me to master the learning process more accurately”, with a score of 4.03 and t value of 7.41; and then item 3”, VR-assisted welding teaching can make me get used to welding and muscle memory”, received a score of 3.95 and t value of 6.73.

In terms of learning satisfaction, the scores of the five questions regarding student learning satisfaction range from 3.95 to 4.08, which all reach significant difference, indicating that most students expressed positive affirmation of their learning satisfaction with VR-assisted welding teaching. Among them, item 2, “VR-assisted welding teaching is more environmentally friendly and of lower pollution”, received the highest score of 4.08 and t value of 7.29; item 1, “VR-assisted welding teaching can improve the personal safety of welding training”, received the second highest score of 4.08 and t value of 6.86; and item 3, “VR-assisted welding teaching saves costs and reduces waste”, received a score of 4.05 and t value of 7.47.

In summary, according to the results, after completing the VR welding course developed by this study, in terms of personnel safety and environmental protection, most students reported generally
positive feelings regarding VR-assisted welding teaching; thus, this course can accurately grasp the learning status of students and improve the efficiency of students’ welding skills learning. In addition, VR welding simulation equipment allows students to repeat the exercises, thus effectively saving the cost of related consumables.

4.3. Analysis of Feedback from Students Learning VR Welding Course

In the experimental teaching process of the “VR Welding Course”, the students’ feedback texts were analyzed, and the key implementation points of each stage of the course were summarized, which are described as follows.

4.3.1. Implement Virtual Reality Safety Advocacy for Welding Field and Practical Courses

According to the purpose of this course, the corresponding VR-assisted teaching activities were planned in advance. In terms of the implementation of the VR welding courses, in order to cultivate students’ professional ethics and qualities, students were required to complete the arrangement and cleaning of the internship site every week. The 1st–2nd weeks include the basic electric welding knowledge units, and mainly introduce the basic knowledge, functions, and operating precautions of electric welding related equipment; among them, the implementation of electric welding related safety and hygiene practices must be emphasized, as students tend to neglect such matters. The 2nd week of this course also presents the application of VR technology to welding-related operating safety rules in a virtual manner, such as wearing protective clothing, protective gloves, and face shields, and confirming automatic electric shock prevention devices, in order that students can experience and implement the requirements one by one, and teachers can design breakthrough tests. Via the VR experience, students can increase their interest in learning, understand the correct implementation of welding operations, and experience the real world scenes and environments they will encounter in the workplace, thus strengthening the learning effect [52].

S0203: “In the first class of the electric welding course, the teacher talked a lot about electric welding related equipment knowledge, electric welding operation safety regulations, and related protective measures.”

S0401: “The teacher asked us to play VR games to experience the correct safety measures before electric welding operations. If you do not wear protective gloves as required, you will be burned, as shown in Figure 3; the welding bead must be cleaned with a slag hammer, as shown in Figure 4.”

Figure 3. Simulate wearing welding protective gloves.
4.3.2. Provide Practice and Guidance for Diversified Virtual and Reality Integrated Welding Practice

The 3rd–4th weeks are the basic electric welding practice units. Due to the limited electric welding equipment, the general practice was to divide the students into groups, the teaching assistant would conduct a demonstration, and then the students took turns to practice welding, as shown in Figure 5. Regarding the issue of students’ first exposure to electric welding operations during this course, and their tendency to fear and resist the sparks, arcs, toxic gases, and noises generated during welding operations, as well as being intimidated by the high degree of skill and stability required for electric welding operations, most first experiences in electric welding receive negative reviews, and result in wasted welding rods, steel, and other costs. Therefore, as the focus is to make students feel safe and secure, this course designed VR electric welding construction unit experience activities before students actually practice electric welding, meaning that students can immerse themselves in the VR welding work environment with sound and light, which prepares them for practical application, as shown in Figure 6. Furthermore, the practice mode of the VR welding equipment has a prompt function, as shown in Figure 7. In other words, the teacher can guide the students’ posture, welding angle, and welding travel speed while simultaneously allowing students to repeatedly experience welding operations and thus learn the correct welding skills and stability. It can be seen that the interactive and immersive nature of VR can increase students’ interest in learning and deepen their knowledge [40].

S0301: “This was the first time for me to do actual welding. Although there was a teaching assistant demonstration, I was afraid of welding by myself. The welding bead was crooked and the welding rod was often stuck, such as in Figure 8. Fortunately, there is VR welding equipment for us to practice first.”

S0602: “VR welding equipment allows us to experience electric welding operations and become familiar with the welding steps and postures. The most important thing is to repeat the practice without fear of injury, let alone damage the equipment.”
4.3.3. Apply VR-Assisted Teaching to Strengthen Students' Proficiency and Application Ability of Welding Skills

The 5th–8th weeks are the advanced electric welding practice units, including horizontal welding, vertical welding, overhead welding, and other welding key points. After the basic exercises in the first two weeks, most students have achieved basic arc starting skills and welding stability and can proceed to learn various welding positions. Before the implementation of these units, this VR electric welding course design provides the students with simulated pre-work exercises in order that they can experience welding in different welding positions as preparation for subsequent actual welding.

The 9th week is the mid-term exam week. Teachers assess students' welding work results and review them based on the quality of the welding bead, as shown in Figure 9, to provide suggestions and answer students' questions. For students who fail meet the inspection standards, this course planned welding remedial teaching, which is equipped with VR welding equipment to provide exercises and tests to help students improve their welding skills. With the application of VR welding equipment,
students can practice continuously by applying the trial and error method, which helps students to solve problems and receive remedial learning [17].

S0503: “In addition to flat welding and horizontal welding, the VR welding equipment can also set the thickness of the plate, so that we can practice a variety of welding modes. This ‘practice makes perfect’ affects the actual welding, and good works can be produced, as shown in Figure 10.”

S0104: “In addition to the practice mode, the VR welding equipment also has a test mode, which can test the stability of our welding, the walking speed of the electrode, and the welding angle, and let us repeat the exercise.”

Figure 9. A student’s mid-term exam works.

Figure 10. A student’s make-up exam works.

4.3.4. Demonstrate Students’ Problem-Solving Ability and Creation Results of the Actual Application of Welding Skills

The 10th–17th weeks are the electric welding project application units, where students are required to complete the work order tasks according to the requirements of the teacher’s curriculum design, including cutting steel to size, assembling and welding according to the design drawing requirements, and applying their learned abilities to practice electric welding and solve problems. The final project is the creative design of products by student groups, which focuses on the completion of practical products for life, and are constructed according to drawings. During this process, students can discover and solve problems by themselves and apply their welding skills to complete a finished product. Students are encouraged to use the VR welding equipment to allow them to see things from different angles and stimulate their ideas and problem-solving skills [32].

The 18th week is the final exam week, and the teacher assesses the students’ welding project products, as shown in Figures 11 and 12. Works are evaluated based on the composition of the finished product, the difficulty of the welding method, the welding defects, and the quality of the weld bead, and suggestions are provided to strengthen the students’ welding abilities.

S0202: Our final project was to design a multi-functional iron frame, which can hold our weekly welding works. The design drawing should be designed according to the size of the plate to facilitate storage and reduce weight.
Although we have learned the skills of electric welding, it is still difficult to actually make the product, because we need to design the product by ourselves, prepare the materials according to the size, and integrate the various welding modes we have learned. Fortunately, the students worked together with labor division, and we actually completed the product.

Figure 11. The students' project works (1).

Figure 12. The students' project works (2).

5. Comprehensive Discussion

This study integrated the results of qualitative and quantitative analyses for discussion, as shown in Table 1. After the 18-week VR integrated welding practice course teaching, most students' post-test scores in the welding practice test were significantly improved [49]. The feedback of students' study sheets and interviews also facilitate an understanding of students' abilities of welding practice. In terms of learning effectiveness, most students had significant improvement in learning progress, learning efficiency, and practical skills. It was generally agreed that the integration of virtual and actual welding practice teaching helped students understand their own learning progress, strengthen their welding skills, improve their welding learning efficiency, and increase their learning interest [39]. In terms of learning satisfaction, most students expressed positive affirmation in terms of learning safety, reducing pollution, reducing costs, assessing learning effectiveness, and strengthening traditional teaching, and agreed that VR-assisted teaching can improve the safety of welding fields and reduce pollution sources, cut down learning costs, provide diversified evaluation of student learning effectiveness, and assist traditional welding teaching [53].

This study conducted observation and interviews to explore using VR technology to assist welding teaching. The results indicate that VR technology can increase the opportunities for students to practice repeatedly and compare with the real situation, which is conducive to learning. Traditional welding practice and VR-interactive teaching can stimulate the interest of learners. The VR-assisted welding teaching system can improve students' acquisition and retention of welding knowledge and can be used as an effective tool for welding teaching [3].

The results of this study echo previous studies and emphasize the effectiveness of VR applied to auxiliary teaching. The VR assisted welding implementation course of this study has been completed.
and can be further extended to other skills verification related courses in the future, in order to carry out teaching experiments to discuss the teaching response and results of both teachers and students. The results of this study can be used to establish diversified teaching modes in the future and integrate teaching aids into auxiliary teaching, which will generate a driving force for innovation. In other words, it is of great importance and necessity to apply situational teaching that integrates VR and professional courses to improve the teaching quality and students’ learning effectiveness.

6. Conclusions and Suggestions

This study explored the feasibility of VR technology-assisted electric welding practice teaching, developed the VR electric welding course and teaching activity design, and implemented experimental teaching to verify its effectiveness. The obtained conclusions and suggestions are as follows:

6.1. Conclusions

The contribution of this study is to integrate the features of VR and innovate its application in the auxiliary teaching of a welding course in order to effectively improve students’ learning effectiveness and satisfaction of welding knowledge. Moreover, in terms of the repeatability and safety of VR-assisted welding teaching, students can practice repeatedly in a safe environment and save the costs of relevant materials, which is sustainable and worth promoting. This research result can be used as the teaching features of this VR welding course as well as the inspiration for the diversified teaching of various courses in the future.

6.1.1. The Final Test Scores of Most Students in Welding Practice Were Significantly Higher Than the Mid-Term Test Scores

This study developed a “student-centered” integrated welding course, which includes site preparation, basic welding knowledge units, basic welding practice units, advanced welding practice units, welding special application units, and mid-term and final tests. In terms of the performance of welding practice, most of the students’ final test scores were higher than their mid-term test scores and with significant difference; thus, after 18 weeks of VR-assisted welding course teaching, the interest, performance, and learning of most students improved, and their practical knowledge was deepened.

6.1.2. Most Students Positively Affirmed the Effectiveness of VR-Assisted Welding Course Teaching

This study planned an 18-week VR-assisted electric welding teaching course, which applied the characteristics of VR immersion, interactivity, and imagination and allowed students to immerse themselves in learning to effectively understand the operation of related electric welding equipment, industrial safety, and health knowledge and learn the skills required for electric welding. In terms of the students’ electric welding learning effectiveness, most students expressed positive affirmation, and all reached significant difference, which shows that most students believe that VR-assisted electric welding course teaching can increase their interest in learning, accurately grasp their learning conditions, and improve their learning efficiency of welding skills.

6.1.3. Most Students Showed Significant Positive Affirmation of Their Learning Satisfaction with VR-Assisted Welding Course Teaching

This study appropriately integrated the simulated teaching of VR welding equipment according to the unit attributes. After 18 weeks of implementation, the results of the student learning satisfaction survey were affirmative and positive, and there were significant differences. These results show that most students were satisfied with the VR-assisted teaching in improving welding personal safety, saving costs, and being more environmentally-friendly, and it allowed students to practice constantly through the trial and error method, helped students learn to solve problems, and strengthened the training of traditional welding courses.
6.1.4. VR Welding Course with Four Key Implementation Points

In the 18 weeks of VR electric welding course experimental teaching, this study collected students’ study sheets and related text materials and summarized four major implementation priorities through qualitative analysis, including implementing the VR safety advocacy of the electric welding field and practical units, providing the practice and guidance of diversified virtual and actual welding practices, using VR-assisted teaching to strengthen the proficiency and application ability of students’ welding skills, and displaying the results of students’ problem-solving abilities and the actual application of their welding skills to the group creations. The effectiveness of the course implementation echoes the quantitative analysis results of this study, and can be used as the implementation focus of this VR welding course.

6.2. Suggestions

With the advent of the information technology era, most students have a high acceptance of emerging technologies. Therefore, this study proposes an innovative educational application of VR technology assisted welding teaching to assist students to turn abstract learning into reality through the experiential learning of VR. In the future, research and exploration can further design diversified teaching activities in combination with teaching empirical theory, which will improve students’ innovative thinking and problem-solving ability and provide teachers and students with more specific on-site learning results. Based on the above research conclusions, the following suggestions are made for schools, teachers, and future research:

6.2.1. Take the VR Welding Course, as Summarized and Developed in This Study, as an Important Reference for Welding Course Planning

This study integrated the three characteristics of VR, interactivity, immersion, and imagination, as well as the welding course syllabus, and developed an 18-week VR welding course. This empirical study was conducted through experimental teaching and questionnaire surveys and has reference value. It is suggested that the results of this study can be a blueprint for course content planning and teaching activity design to meet the needs of student ability training and industrial personnel when VR-assisted electric welding related practical courses are planned and implemented by the universities of science and technology.

6.2.2. Cultivate Teachers’ VR Knowledge and Skills to Assist in Practical Teaching

The integration of emerging technology-related technologies into teaching is a future trend. According to the summarized conclusions of VR technology-assisted electric welding course teaching, this study reviewed the learning effectiveness and satisfaction of students and found that learning effectiveness was improved, the performance of personal safety was improved, and the cost of consumables was reduced. Therefore, the innovation of practical teaching in the universities of science and technology must first start with changing how teachers think and improving their abilities by encouraging teachers to participate in innovative teaching practice workshops and forums to cultivate their new technology-related knowledge, which can be taken as the basis for improving the effectiveness of innovative teaching.

6.2.3. Have Discussions on Experimental Teaching of Related Research Topics

As the application of VR technology to practical skills related teaching is one of the important topics regarding the application of emerging technology to education, it is recommended to refer to the results of this study and apply them to welding courses, plan an experimental group and a control group, and compare the effect of different teaching methods on students’ learning effectiveness. In addition, VR technology can be applied to other practice courses to explore the effectiveness of
VR-assisted teaching by referring to the research process of the development of the VR-assisted welding practice course in this study.

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