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Virtual reality platforms for K-12 STEM education

Tyler Ward[a], Jorge A. Ortega-Moody[b], Sam Khoury[c], Mykelti Wheatley[d] and Kouroush Jenab[e*]

[a]*Department of Engineering Sciences, Morehead State University, Morehead, KY 41139, United States*
[b]*School of Engineering, Embry-Riddle Aeronautical University, 1 Aerospace Boulevard, Daytona Beach, FL 32114, United States*
[c]*Academic Affairs, Spring Hill College, Mobile, AL 36608, United States*
[d]*Department of Computer Science & Electronics, Morehead State University, Morehead, KY 40351, United States*
[e]*Department of Engineering Sciences, Management, Morehead State University, Morehead, KY 40351, United States*

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A B S T R A C T

Providing K-12 students with proper science, technology, engineering, and math (STEM) education is important to ensuring an innovative and prosperous economy. A highly skilled STEM workforce can lead to increased productivity and competitiveness, which can lead to a host of new ideas being researched and developed. STEM workers make added-value products, build bridges and roads, and conduct lifesaving medical research, among other important activities. The use of virtual reality (VR) technology for both education and workforce training has grown in recent years. VR technology can accelerate these processes at maximum efficacy and minimum costs and can have a significant impact on productivity gains, earnings, new jobs, innovation through research and development, and high-growth industries. This paper presents the development of a series of VR modules using the Unity game engine, the HTC VIVE Pro VR headset, and the Hi5 VR glove for the purposes of K-12 STEM education. Specifically, these developed modules have been designed to instruct K-12 students on topics related to motion and heat, with future goals to expand the modules to cover topics related to light, magnetism, electricity, radioactivity, sound, and waves. This paper will cover the methodology and design considerations that went into developing these modules, with a focus on how these modules relate to various learning strategies as well as with existing research on the use of VR in K-12 education.

1. Introduction

The late 1990s and early 2000s ushered in massive technological innovations at a breakneck pace. Rapid improvements in fields such as robotics, artificial intelligence, and quantum computing led the founder of the World Economic Forum, Klaus Schwab, to declare in 2015 that the world had entered what he called the "Fourth Industrial Revolution" (Schwab, 2015). One of the major contributing factors to this rapid technological advancement is education in STEM subjects at the K-12 level (Forawi, 2018)

While still generally being considered a global leader in education, the United States has stagnated in both science and math on the Program for International Student Assessment (PISA) since 2003. In 2018, the most recent administration of the PISA test, the U.S. ranked 11th out of 79 countries in science, and 30th in math (OECD, 2023a; OECD, 2023b). It has been estimated that if U.S. students' test scores in math and science were as strong as their counterparts around the world, the economic impact on the U.S. economy would be a 4.5% growth within 20 years (Hanushek, 2012). In a ranking of the U.S. states by K-

* Corresponding author. Tel.: +1-606-783-9339 Fax: +1-606-783-5030

E-mail address: k.jenab@moreheadstate.edu (K. Jenab)

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12 achievement on a standard 'A+' to 'F' scale, the average ranking of the U.S. nationally was a 'C,' with no state achieving above a 'B' ranking (EdWeek Research Center, 2021). This lacking educational performance seems to be having an effect on the U.S., as it placed 10th in the 2022 Competitiveness Report after having placed 1st in 2018 (IMD World Competitiveness Center, 2022).

While most people would likely associate VR technology with its video game applications, it has many other uses, and in recent times has shown potential in its uses for education. VR platforms can provide outstanding visualizations for STEM scenarios, which can be beneficial in K-12 education. When used for STEM education, VR platforms can increase the engagement of K-12 students and can spark interest in pursuing higher education STEM programs in fields such as automation and robotics.

This research paper covers the development of four VR K-12 education modules built with the Unity game engine with support for the HTC VIVE Pro VR headset and the Noitom Hi5 VR glove. These modules employ learning strategies and knowledge acquired from current literature on the topic of using VR for educational purposes to provide an exceptional method for students to learn STEM concepts related to motion and heat. This paper focuses on the methodology and design consideration used to design these modules and discusses the learning strategies used to ensure their effectiveness at properly educating K-12 students.

2. Literature Review

The influence of early exposure to STEM concepts on workforce development and socioeconomic prosperity has made the development of effective K-12 STEM programs a national educational priority (Miller et at., 2018). Of the four subjects incorporated into the 'STEM' acronym, research shows that engineering concepts are the most challenging for K-12 students to learn (Miller et al., 2018; Pellas et al., 2020; Williams, 2015). There are various factors that contribute to this lack of adequate engineering education, among which include lack of teacher education on the subject, lack of integration into existing science and math courses, and lack of funding and time for implementation (Williams 2015). Potential solutions to address these issues regarding engineering education include demonstrating the practical application of engineering concepts to the students and employing innovative methods to teach the content (Williams, 2015). Once such method with potential to boost student engagement and performance in K-12 engineering lessons is the use of VR technology as a teaching tool (Pellas et al., 2020). An example of VR technology being used for K-12 engineering education is described in (Dinis et al., 2017), where VR was used to educate K-12 students on civil engineering concepts. In this study, after interacting with the VR modules the researchers had designed, the K-12 students had a better understanding of the job requirements of a civil engineer than they did prior to using the modules. Many studies support the claim that the use of VR technology to support instruction in K-12 environments boosts the learning potential of K-12 students (Chen et al., 2005; Dinis et al., 2017; Ferro et al., 2021). Even in studies where it was found that VR modules did not influence individual students' attitudes towards either the course or educational games, using the modules was found to have a positive impact on team performance and collaborative learning (Terzidou et al. 2016). Across studies, it was found that VR technology is most influential in education when it is used in tandem with proper instructional principles and design (Bohné et al., 2021; Chen et al., 2005).

Many studies discuss the impact of different instructional strategies and designs on the quality of VR-based education (Dalgarno & Lee, 2009; Huang et al., 2010; Scott et al., 2017). Four simple principles to assist VR course design are given in (Huang et al. 2010) as: the student should learn from interacting with an artificial real environment, their creativity should be promoted based on their problem-solving ability, they should be motivated to learn, and VR should be used as a tool to promote this learning. A more expansive list of affordances that should be considered when designing VR modules for education are given in (Dalgarno & Lee, 2009), which lists the affordances as: VR modules should facilitate learning tasks that lead to the development of enhanced spatial knowledge representation of the explored domain, facilitate experiential learning tasks that would be impractical or impossible to undertake in the real world, increase intrinsic motivation and engagement, improve knowledge transfer and skills to real-world situations through learning contextualization, and lead to richer and more effective collaborative learning than is possible with traditional methods. Different types of instructional strategies (game-based, simulation-based, and exploratory), content delivery methods (interactive 3D and 2D objects), presentation styles (multimedia and text), and navigation methods (direct guidance, hiding/disabling/removing, highlighting, generating, and sorting) are identified and discussed in (Scott et al, 2017).

In addition to planning the desired instructional strategies to be used when creating VR-based learning modules, research also shows that attention must be paid to the pedagogical agents that the students will be interacting with in the module itself. A pedagogical agent in this context can be loosely defined as a virtual tutor that guides the student through the completion of the VR module (Harley et al., 2018). The effectiveness of pedagogical agents to improve learning has been studied, with (Harley et al., 2018) finding that students were both willing to engage with and benefit from interactions with pedagogical agents when directions, immediate feedback, and multiple attempts are provides. Another study found that students were more likely to experience positive outcomes from working with VR-supported learning environments when they were able to interact with pedagogical agents that were of the same gender as themselves (Makransky et al., 2018). One final aspect that needs to be addressed when designing VR modules for education is how different types of student learners react to the integration of VR technology in their traditional learning environments. It has long been known that the integration of VR into K-12 education has had more of a positive effect on low-performing students than their high-performing counterparts (Winn et al., 1997), however, recent studies show that certain changes can be made to VR modules to reduce this learning gap.

3. Methodology

This research project presents the development of multiple learning modules for use with VR technology to facilitate enhanced STEM education for K-12 students. This section will detail the considerations that went into selecting the STEM concepts to build VR learning modules around, potential benefits they offer, and how well they align with K-12 learning objectives. Following sections will detail what design considerations were made during the development of the modules and will cover module development itself.

3.1. Technology Selection

Research has shown that the HTC VIVE and Oculus Rift series of VR headsets are the most popular headsets in educational environments (Ali et al., 2019). In a direct comparison of system capabilities between the two headsets, both were determined to have adequate visualization capabilities in environments of varying luminance and good precision of positioning, while the HTC VIVE was found to have better framerate than the Oculus Rift, better handling on loss of line of sight issues, a faster time for object interaction in the virtual environment, and was overall better-received by the study's test group (Suznjevic et al., 2017). For this reason, the HTC VIVE headset, specifically the HTC VIVE Pro, was selected as the VR headset to be used in this research project. The Unity game engine was selected to develop the modules due to how well the capabilities of the engine align with the project's objectives and requirements.

3.2. Contribution of the Technology to the Development Process

The Unity game engine has a user-friendly interface, versatility in accommodating diverse learning needs, and compatibility with the chosen VR technology. Included in Unity's robust development ecosystem is an extensive asset store that expedited the process of content creation while preserving a high standard of quality. The engine's seamless integration with VR devices allowed for optimal performance and immersive experiences, which are essential for effective K-12 STEM education. Additionally, Unity has been widely adopted in industry, which allowed access to a wealth of resources and professional expertise, facilitating timely solutions to potential challenges. The HTC VIVE Pro has a high-resolution display that provides a detailed and realistic visual representation of virtual environments. It provides a wide field of view and accurate tracking, which allows students to become fully immersed in the virtual environment. This level of immersion can help students visualize abstract or complex STEM concepts. This research project also employs the use of the Noitom Hi5 VR Glove for finger tracking. Research shows that when such finger tracking technology is employed in virtual environments, users report more positively on their VR experience (Debarba et al., 2022; Jha et al., 2021; Lee et al., 2019). This glove allows students to use their hands for natural and intuitive interactions within the virtual environment. This means that students can grasp, manipulate, and examine objects as they would in the real world. Natural interaction promotes a sense of presence and can facilitate a deeper sense of engagement and understanding of the learning materials. The Noitom Hi5 VR Glove is also designed to work seamlessly with the HTC VIVE Pro headset, meaning that development time was saved by leveraging this existing hardware instead of developing proprietary technology. The VR technology used in this research project offers a multi-sensory experience by combining visual, auditory, and haptic feedback. This interaction of sensory cues can enhance the learning process by stimulating multiple senses simultaneously, leading to a more immersive education experience. In addition, both the HTC VIVE Pro and the Noitom Hi5 VR Glove give real-time feedback to students' actions in VR. This feedback can help students understand the consequences of their actions, fix mistakes, reinforce learning outcomes, and can accelerate the learning process and promote self-directed learning. The HTC VIVE Pro and Noitom Hi5 VR Glove used in this research are shown in Fig. 1.

(a) (b)

Fig. 1. (a) The HTC VIVE Pro headset used in this research project. (b) The Noitom Hi5 VR Glove used in this research project

3.3. Topic Selection

The first step in the process of creating the VR modules was to identify which STEM concepts would be covered. Of the many concepts taught to K-12 students by educators, the following were determined to have the most potential for adaptation into VR-based learning modules: motion, heat, light, magnetism, electricity, radioactivity, sound, and waves. Of these identified concepts, this paper covers the development of VR learning modules for topics relating to motion and heat. These two concepts are fundamental in physics and are some of the earliest STEM concepts taught to K-12 students. They are also strongly cross-disciplinary, with applications in fields such as mathematics, engineering, and chemistry, which make them strong contenders for VR modules aimed at enhancing STEM education.

K-12 topics related to these concepts can range in complexity, lending themselves well to the development of modules that cater to different grade levels within the K-12 ecosystem. In addition to this variation in complexity, motion and heat as concepts are dynamic in nature, and are often taught to K-12 students with lab-style assignments. This suitability to experiential learning demonstrates the potential effectiveness of VR to enhance student learning in these areas, as VR technology can simulate realistic scenarios and allow students to interact with and observe these concepts in action, which will promote deeper understanding and engagement with the material.

3.4. Benefits of Motion and Heat Topics in VR Education

One of the main ways that VR can aid STEM education is by offering enhanced visualization. Motion and heat can be abstract concepts that can be difficult for K-12 students, especially those on the younger side, to understand. VR provides unique methods to visualize these concepts, by using vibrant colors, animations, and effects to facilitate better comprehension and retention of the subject matter.

VR offers many more educational benefits than just its visualization capabilities. VR modules offer students interactive and engaging experiences, allowing them to manipulate objects, observe cause-and-effect relationships, and conduct virtual experiments related to motion and heat. This hands-on approach fosters active learning and encourages students to become active participants in their STEM education.

With active learning, there can be concerns about what happens when a student makes a mistake. In our VR learning modules, students need not worry about breaking any of the experiment materials, which could enhance their capacity to try different things, observe the outcomes, and learn from their mistakes. These qualities could be discouraged in a traditional setting due to limited resources, fragility of materials, or the amount of time it takes to re-set up an experiment. In the VR modules discussed in this paper, if a student makes a mistake, all they have to do to reset the experiment is to press a single button, which will reset the entire module back to the beginning.

The repeatability of the experiments in the VR modules also addresses another important concern that often plagues educators: budget. K-12 teachers, especially those who teach STEM subjects that rely on lab-based coursework, have notoriously small classroom budgets, and often have to pay for items out of their own pocket. Our VR learning modules can help ease monetary concerns because after an initial investment in the VR technology, no further monetary investment is needed. Our modules can also be played without the use of VR technology and can run on regular lab PCs.

A final benefit offered by VR technology is the number of opportunities they open up for educators to enhance their courses. It is important to note that our VR modules are not meant to replace the very important role of a teacher in a K-12 student's life. These modules are designed as teaching aid that can be incorporated into curriculum in a variety of ways, be it as the primary method of experimentation in their classes, as a supplement to traditional lectures and labs, or as a method of learning reinforcement for students in need.

4. Design Considerations

4.1. General Considerations for Module Design

The VR modules were designed for K-12 students in mind, so consideration was paid to ensuring that the content and complexity of the modules align with the intellectual capabilities of K-12 students. Clear learning objectives were defined for each module, that outlined the specific knowledge and skills that students should acquire through their engagement with the virtual environment. Each of the learning objectives were based on their alignment with established STEM curriculum standards, ensuring that the content covered in the VR modules corresponds to topics taught in traditional classrooms.

The modules were designed to be interactive and engaging, providing hands-on experiences and simulations that promote active learning and student participation, while also being structured to introduce concepts gradually, building upon previously knowledge and providing appropriate scaffolding to support student learning and understanding.

4.2. Usability, Accessibility, and User Experience

The user interface of the VR modules was designed to be intuitive and user-friendly, allowing students to navigate and interact with the virtual environment with ease. The modules provide clear instructions and guidance to users, ensuring that students understand how to interact with the virtual environment and complete the learning activities. In line with the findings of (Makransky et al., 2018), an option was also added to allow the students to change whether the voice of the virtual instructor (VI) guiding them through the modules was a male or female, to suit their preference. Considerations were made to accommodate diverse learners, including features such as adjustable text size, captioning for audio, and alternative modes of interaction to cater to different learning styles or physical activities. The design considered the availability and compatibility of the necessary hardware and software, ensuring that the modules can be accessed and utilized by a wide range of students and schools.

4.3. Pedagogical Theories and Instructional Strategies

Research into using VR technology for educational purposes generally falls into two categories: technical research and pedagogical research. On the technical side, researchers develop and employ VR technologies for education, while researchers on the pedagogical side study the application of various pedagogical theories and instructional strategies to VR education and examine their effectiveness at enhancing student learning. In the existing literature, there is a larger focus on technical matters surrounding VR in education than there is on pedagogy (Huang et al., 2010). This research paper seeks to offer in-depth details on both the technical aspect of the technology used in our development of VR modules for K-12 education, and the pedagogical theories and instructional strategies that were employed during the design of the lesson plans for each module. A diagram depicting the pedagogical theories and instructional strategies employed during the development of our VR modules for K-12 education is shown in Fig. 2.

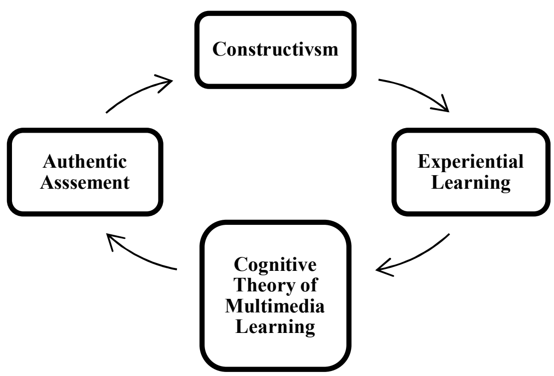


Fig. 2. The pedagogical theories and instructional strategies used in the VR modules for K-12 education.

Constructivism is an educational philosophy that expresses the importance of students taking an active role in their education. Research shows that constructivism is one of the most applicable educational philosophies to VR education (Huang et al., 2010). It promotes hands-on, experiential learning that allows students to physically explore concepts and engage in problem-solving tasks, which makes constructivism an ideal instructional strategy to employ for our K-12 VR education modules.

To properly align with this constructivist ideology, our modules rely heavily on experiential learning as an underlying principle. This focus on experiential learning also satisfies one of the educational affordances offered by 3-D virtual learning environments as identified by (Dalgarno & Lee, 2009). In our modules, students actively engage with the virtual environment, manipulate objects inside it, conduct experiments, and solve problems in a hands-on manner. Through these experiential learning experiences, our modules aim to spark curiosity, enhance critical thinking skills, and empower students to become active participants in their educational journey.

In addition to constructivism, another pedagogical theory that forms the basis of our modules is the Cognitive Theory of Multimedia Learning (CTML) (Mayer, 2005). This pedagogical theory is based on the idea that instructional messages for multimedia learning are more effective when they are designed in line with how the human brain works. Another main component of this theory is the idea that as a student's cognitive load increases, their internalization of material and knowledge transfer is reduced.

Studies show that when implemented improperly, VR systems can result in a decrease in student learning capabilities due to increased cognitive load on their users (Albus et al., 2021; Zhang and Liu, 2023). This can be due to developers getting lost in the creative process of designing VR modules for educational purposes and ending up with an unnecessarily complex visual design for the virtual environment (Albus et al., 2021; Zhang and Liu, 2023). One proposed method of negating user confusion due to the complex visual nature of VR is signaling, which is a means of providing attentional guidance to users to reduce cognitive load related to attempting to figure out what actions to perform inside the virtual environment to progress the activity (Albus et al., 2021; Mayer, 2005).

In line with the CTML, the goal of our VR modules for K-12 education is to reduce the cognitive load on the students, to ensure the most effective learning environment. We seek to accomplish this in two ways, the first being keeping the visual design of our modules simple and intuitive, and the second being the application of signaling. In our modules, we employ signaling using three different types of information: visual, auditory, and textual.

Visual signaling in the modules is given through the use of vibrant colors and shapes indicating where in the virtual environment the student is supposed to move to continue the lesson. This visual signaling is combined with auditory and textual information to ensure that the message of what the user is supposed to do is clear. The auditory signaling comes in the form of a VI that is conducting the lesson much like a traditional educator would. First, the VI introduces the concept that will be covered by the module, next it introduces the VR experiment the student will be conducting in the module, and then finally it guides the student through the experiment, giving clear instructions on what actions the user is supposed to perform. The textual signaling is given in the form of subtitles that appear on the screen as the VI is speaking, providing the same background and instructions for students who learn better by reading information themselves as opposed to having it dictated to them. An example of visual signaling in one of the modules is shown in Fig. 3.

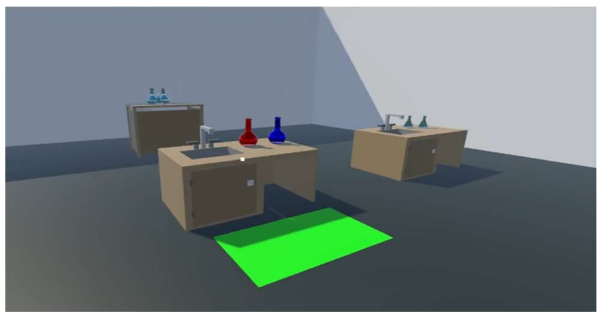


Fig. 3. An example of visual signaling in one of the modules. The green square on the floor represents the location that the student is supposed to move to continue the lesson

The final instructional strategy used in our modules is an adherence to the principle of authentic assessment. Authentic assessment is a method of assessment that is designed to measure a student's capabilities in a so-called “authentic” setting such as in a scenario that they may encounter if they were actually working in a particular field. Studies have shown that the implementation of VR technology into STEM education for K-12 students has potential as a tool for authentic assessment of students (Koh et al., 2022).

To facilitate proper authentic assessment of students’ learning capabilities, our modules employ both formative and summative assessments. Formative assessments are constantly given in the form of real-time feedback for the students’ actions within the VR module, allowing students to understand when they have made a mistake and need to restart the module. Summative assessments are offered at the end of each module after the student has successfully completed the experiment.

4.4. Alignment with K-12 Curriculum and Learning Standards

The Next Generation Science Standards (NGSS) were proposed in 2013 through a collaborative effort by 26 U.S. states and several education-focused professional organizations. The goal of the NGSS was to create a set of “research-based, up-to-date K-12 science standards” (NGSS Lead States, 2013). Since their inception, these standards have been implemented in many states and schools across the country, and it is these standards that served as the basis for the learning objectives of the VR modules discussed in this research paper.

The NGSS breaks up its standards by elementary, middle, and high school grade levels. As already discussed, motion and heat are concepts that can vary in complexity depending on the topic being covered, so it should come as no surprise that there are standards set by the NGSS for educating K-12 students on topics related to motion and heat across each of the three grade levels. The VR modules discussed in this paper do not set out to meet every single NGSS standard for motion and heat education, but they do address several standards for each grade level. The standards (NGSS Lead States, 2013) that are directly addressed by the VR modules are given in Table 1.

Table 1
NGSS Standards (NGSS Lead States, 2013) Met by the Modules

Standard	Description
K-PS2-1	Plan and conduct an investigation to compare the effects of different strengths or directions of pushes and pulls on the motion of an object.
K-PS2-2	Analyze data to determine if a design solution works as intended to change the speed or direction of an object with a push or pull.
MS-PS2-2	Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.
HS-PS2-1	Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
HS-PS3-4	Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined with a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).

The VR modules also partially meet some of the other NGSS standards. These partially met standards are shown in Table 2 with detail on how the VR modules partially meet the standards. Ideas on how K-12 educators can expand on these VR modules using traditional methods in order to fully meet these standards are given in later sections of this paper.

Table 2
NGSS Standards (NGSS Lead States, 2013) Partially Met by the Modules

Standard	Description	Parts of Standard that are Met
4-PS3-2	Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.	One of the VR modules allows students to make observations and provide evidence that energy can be transferred from place to place by heat.
MS-PS1-4	Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.	One of the VR modules enables students to predict and describe changes in temperature of a pure substance when thermal energy is added or removed.
MS-PS2-1	Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.	One of the VR modules centers on the Third Law of Motion but does not involve two colliding objects.
MS-PS3-3	Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.	One of the VR modules centers on heat transfer, and there are various items that both can and cannot transfer thermal energy.
MS-PS3-4	Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the	One of the VR modules allows students to investigate the energy transferred by the temperature of the sample.

5. Module Development

5.1. Overview of the Modules

Even though they may not formally be introduced to them until middle school, K-12 students are exposed to the general ideas of motion and forces formulated by Newton's laws of motion from kindergarten, with lessons focusing on concepts such as gravity, friction, and simple machines. The laws of thermodynamics, while slightly more advanced than the laws of motion, are important for K-12 students to understand topics such as heat transfer, temperature, and energy conservation. Since there are three and four laws of motion and thermodynamics respectively, there is ample material to be covered in the VR learning modules. The goal of this research project was to design VR modules that would be fun and engaging to the students, so for that reason, each of the modules will be simulations of popular science experiments commonly practiced by K-12 students. Each of the selected science experiments that were simulated will be discussed below.

1) **Coin Drop Experiment**

The Coin Drop Experiment is a popular science experiment typically conducted in elementary or middle school that is meant to demonstrate the principle of inertia. The general process for the experiment is as follows:

a) The student will assemble a series of props so that there is a card on top of a cup, with a coin on top of the case.
b) Then the student will move the card at different speeds. Due to inertia, if the student moves the card slowly, the coin will remain balanced on the card, demonstrating the "an object at rest will remain at rest" portion of Newton's first law of motion. However, if the student moves the card quickly, the force of gravity will act on the coin, causing the coin to drop into the cup.

2) **Wagon and String Experiment**

The Wagon and String Experiment is an experiment to demonstrate the second law of motion in action. The general process for the experiment is as follows:

a) The student will attach a string to a small wagon.

b) With nothing in the wagon, the student will attempt to pull the wagon and make a note of the resistance they encounter.
c) Next, the student will add weight to the wagon, and repeat the previous step.
d) The student will continue adding weight to the wagon and attempting to pull it until the string snaps. This demonstrates the principle of the second law of motion where the force required to move the wagon increases with the mass, eventually causing the string to snap when the force required to move the wagon exceeds the strength of the string.

3) **Balloon Rocket Experiment**

The Balloon Rocket Experiment is designed to teach K-12 students about the concepts of action and reaction, which are covered under Newton's third law of motion. The general process for this experiment is as follows:
a) The student will attach a string securely to an object.
b) They will then thread the feed the string through a straw or a similar cylindrical object.
c) The student will then blow up a balloon, holding it closed with one hand while securing the balloon to the straw with tape with the other.
d) The student will then attach the loose end of the string securely to another object.
e) The student will release the balloon and watch as both the balloon and the straw fly along the string, demonstrating the third law principle that every action has an equal and opposition reaction.

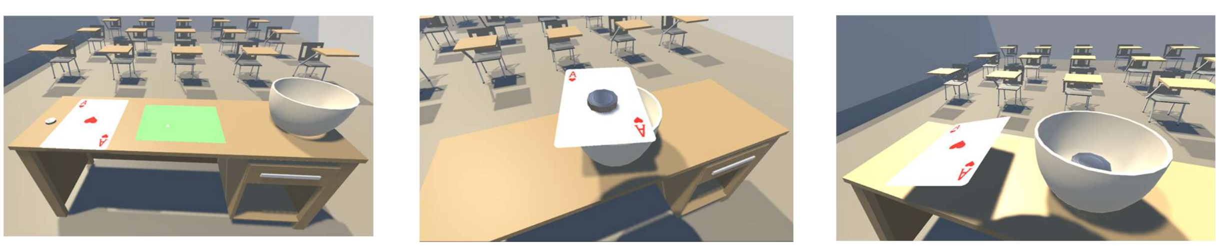
4) Thermal Equilibrium Experiment

The experiment meant to teach students about heat-related concepts is designed to demonstrate the zeroth law of the thermodynamics, which states that two systems, when in thermal equilibrium with a third system, are also in thermal equilibrium with each other. The general process of this experiment is as follows:
a) The student will fill three containers, one large and two small, with water of different temperatures.
b) Then, the student place both of the smaller containers into the larger container and measure the temperature of the water inside the containers.
c) Eventually, due to the law of thermodynamics, the temperature of all of the liquids will be in equilibrium with each other.

5.2. Key Features and Functionalities

In each of the modules, the student's position is locked, although they can still look around. This is to cut down on unnecessary distractions that could hamper the student's understanding of the module and what is expected of them. As soon as the module starts, the VI begins the lesson. The introductory content of the lesson informs the student what concept the module will be exploring, briefly explains the general idea of the STEM concept, and issues the first instruction to the student.

1) **Coin Drop Module**
The student starts in a corner of the room, and is told to approach the desk in front of them. On the desk are the three items necessary for the student to complete the experiment: the cup, the card, and the coin. Because of the nature of VR and the limitations of the technology, if the items were kept to real-world scale, they could be too difficult to interact with, especially something as small as a coin. The VI will guide the student through the experiment, explaining what action the students are supposed to take and ho these actions relate to the module. At the end of each module, positive reinforcement is given to the student, with the VI congratulating the student on completing the module and encouraging them to come up with their own experiments to demonstrate the concept in the module. This provides a good launching off point for a traditional instructor to assign homework for the student to design their own experiment. Images showing several steps the students participate in to complete the module are shown in Fig. 4.



(a) (b) (c)

Fig. 4. (a) The desk in the initial state of setup, the green square represents the location the student it to move the cup. (b) The desk after the student has successfully set up the experiment. (c) The end state of the module after the student has quickly moved the card to send the coin into the cup

1) **Wagon and String Module**

The wagon and string experiment employs more gamification techniques than the coin drop module. In this module, the student is placed beside an empty wagon and is instructed to pull the wagon to see how easy it is. Next, the student is instructed to walk to a variety of crates of different weights and informed that some combination of weights will cause the string to snap. The puzzle that the student will have to solve is which combination of weights will snap the string. This puzzle-like nature of the module will increase student knowledge through the engagement with the game of identifying weights and testing them out on the wagon and string will drive home the meaning of Newton's second law of motion. The benefits of gamification in VR learning modules are discussed in (Marougkas, 2021). Images showing several steps the students participate in to complete the module are shown in Fig. 5.

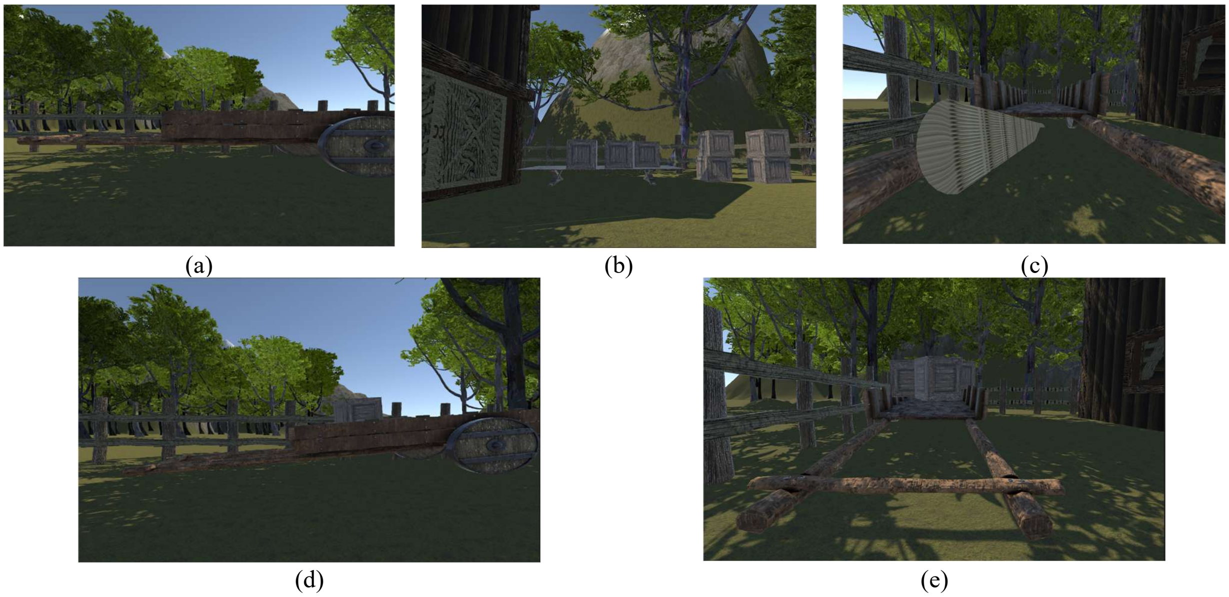


Fig. 5. (a) A side view of the wagon that forms the basis of the experiment. (b) The weights that the student will be placing in the wagon. (c) A view of the student pulling the empty wagon using a string. (d) The effect of the weight on the wagon. (e) The wagon with the maximum weight added. Once this has been achieved, the string will break when the student attempts to pull the wagon

1) **Balloon Rocket Module**

The balloon rocket module is designed to perform exactly as the traditional experiment would. A balloon, string, and straw are located at the back of the room, and the students must locate two points in the room where they will attach the string. Once they do this, they are asked to attach the straw and balloon to the string. Once all the elements are attached, the student is asked to inflate the balloon, but they will have to be careful because if they inflate the balloon too much, it will pop. Once the experiment is set up, the VI explains the third law of motion and how it relates to the experiment the student just performed. Images showing several steps the students participate in to complete the module are shown in Fig. 6.

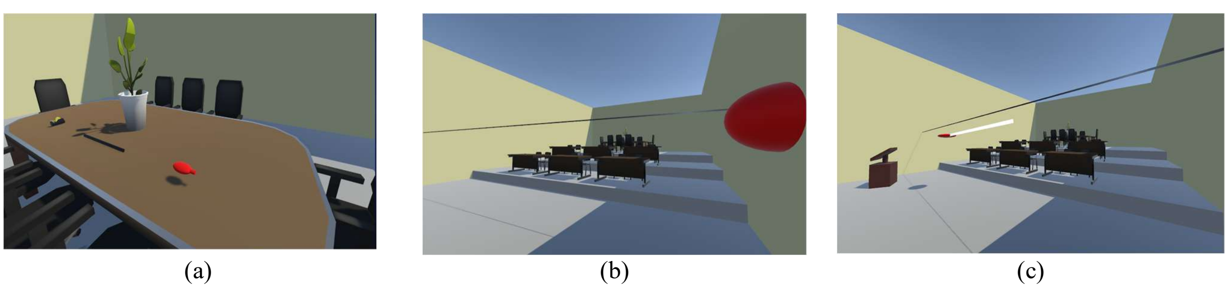
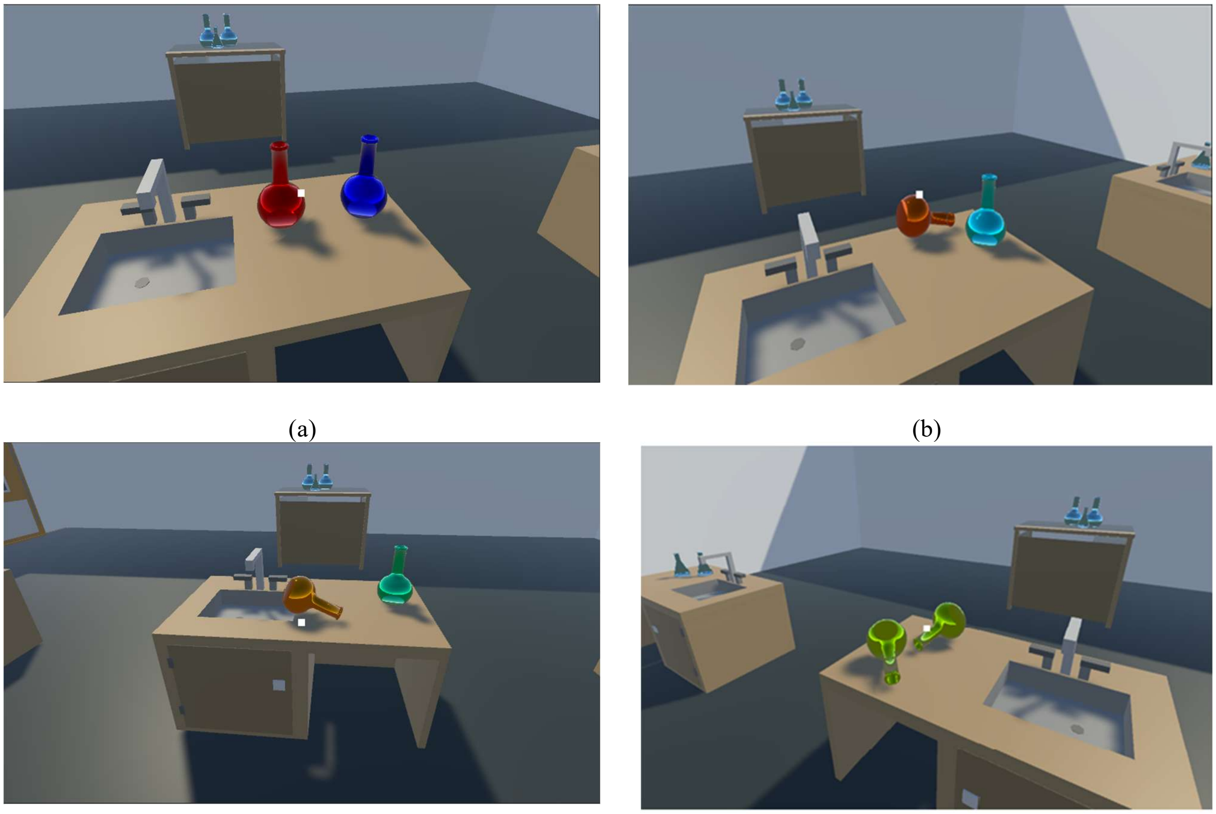


Fig. 7. (a) The initial desk setup of the balloon rocket module. (b) The module after the student has setup the experiment, attached all of the elements and inflated the balloon. (c) The module after the student has initiated the balloon rocket

1) **Thermal Equilibrium Module**

The thermal equilibrium module is a basic module that simply asks the student to touch two test tubes containing liquids of different temperature. The module employs visual signaling to emphasize the transfer of heat. There are four different states for the colors of the tubes: a starting state, and ending state where the system is in equilibrium, and two states where heat transfer is occurring. As the colors change, the pedagogical agent is explaining the zeroth law of thermodynamics to the student. Images showing several steps the students participate in to complete the module are shown in Fig. 8.



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

Fig. 8. (a) The initial starting temperatures of the liquid samples (b) The first heat transfer phase. (c) The second heat transfer phase. (d) The final temperatures of the liquid samples

6. Expansion and Future Goals

This paper has presented the design considerations and methodology used to create VR education platforms for K-12 STEM education. At this point in our research, the focus has been to develop modules related to the STEM concepts of motion and heat. The immediate avenue for future research is to develop more modules for heat-related concepts, specifically the first, second, and third laws of thermodynamics. Moving past motion and heat, this section will present various possibilities for expanding the work presented in this paper to other topics within STEM education, specifically light, magnetism, electricity, radioactivity, sound, and waves. Expanding the VR modules to cover topics related to light can provide students with immersive experiences that can offer them a unique perspective on how light behaves. Such modules can be effective tools for encouraging a deeper understanding of optical phenomena by simulating concepts such as reflection, refraction, and the formation of images through lenses and mirror. The modules can also present students with a fun and engaging way to observe how light interacts with an environment by allowing them to interact with simulations of different materials and wavelengths, which can enhance their comprehension of the topic. VR modules that focus on magnetism and electricity can provide students with an exciting opportunity to explore the complex and often abstract principles of electromagnetism, electric circuits, and magnetic fields. Through interactive virtual experiments, students can actively manipulate virtual components, observe magnetic interactions, and gain a fundamental understanding of electric circuits. Such immersive experiences have the potential to bring abstract concepts to life in fun and interesting ways, and to stoke a passion for learning STEM concepts. Teaching radioactivity through VR modules can be a valuable tool in explaining concepts related to nuclear physics and radioisotopes. By employing virtual simulations, students can witness the decay of radioactive materials, learn about radiation shielding, and explore the diverse practical applications of radioactivity across various fields. This not only enhances their theoretical knowledge but also enables them to see the real-world implications of these scientific phenomena. Sound is another STEM concept that can be benefited by the implementation of VR technology. Students can get a hands-on understanding of how sound waves behave in different mediums through learning modules that concentrate on wave properties, pitch, frequency, and resonance. Comprehension of sound-related content can be enhanced through interaction with virtual sound sources and dynamic simulations. Since the concept of a wave is present in magnetism, electricity, and sound, it is logical to develop VR learning modules focusing on different waves, such as electromagnetic waves, water waves, and seismic waves. The inclusion of various types of waves in the modules can offer students a comprehensive understanding of wave behavior and their broad applications. Virtual simulations provide an opportunity to visually illustrate complex concepts, including wave propagation, interference, and the countless wave-based technologies that exist.

In conclusion, there is immense potential for VR technology to revolutionize STEM education. By expanding the VR modules discussed in this paper to cover a range of topics such as light, magnetism, electricity, radioactivity, sound, and waves, we can provide students with truly immersive and transformative learning experiences. These future goals would make a step forward in making STEM education more engaging, accessible, and impactful for students of all ages.

7. Conclusion

In conclusion, this research paper has presented the development of a series of VR modules for K-12 STEM education, with a focus on topics related to motion and heat. The methodology employed in the development process involved careful consideration of technology selection, the contribution of VR to the learning experience, topic selection, and the benefits of motion and heat concepts in VR education. Additionally, design considerations encompassed aspects of module design, usability, accessibility, user experience, and alignment with pedagogical theories and instructional strategies.

The main findings of this research highlight the immense potential of VR technology in K-12 STEM education. The VR modules offer immersive learning experiences that engage students, stimulate multiple senses, and enhance visualization of abstract concepts. By providing interactive and hands-on experiences, students can manipulate objects, conduct virtual experiments, and observe cause-and-effect relationships, ultimately fostering a deeper understanding of scientific principles. The potential of VR technology for use in K-12 STEM education is promising. With VR platforms capable of supplementing traditional teaching methods, educators can create engaging and dynamic learning environments that cater to diverse learning styles and abilities. The integration of VR into the curriculum can potentially increase students' interest in STEM subjects, leading to a greater number of students pursuing higher education and careers in science and technology-related fields. Furthermore, this research paves the way for future developments and advancements in the field of VR-based education. As technology continues to evolve, VR platforms may become more accessible and affordable, reaching a wider range of educational institutions and students. Expanding the scope of the VR modules to cover additional STEM topics, such as light, magnetism, electricity, radioactivity, sound, and waves, could further enrich the learning experiences and encourage interdisciplinary exploration.

Ultimately, the adoption of VR technology in K-12 education holds the potential to positively impact the workforce of the future by fostering a highly skilled STEM workforce. Equipping students with the necessary knowledge and skills through immersive learning experiences can lead to increased productivity, innovation, and competitiveness in the global economy. As VR-based education progresses, it will undoubtedly contribute to shaping a more technologically proficient and scientifically aware society, laying the foundation for a thriving and prosperous future.

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