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Article

Virtual Reality of Labless Foundry and Heat Treatment for Next Industrial Training

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Abstract. This study presents an innovative Virtual Reality (VR) application tailored for educating users on Foundry and Heat Treatment operations. Its primary objectives encompass the creation of a secure and lifelike learning environment while ensuring accessibility. The development process was a meticulous fusion of technology, incorporating the Unity engine, 3D modeling, and seamless Salesforce integration, all grounded in extensive research. The VR application's structure strategically subdivides these industrial processes into four stations: Molding, Furnace, Workbench, and Heat Treatment, with each station's execution steps comprehensively outlined in corresponding tables. This detailed approach empowers users to engage directly in these operations, making it a valuable educational tool. The study's significance extends to the realm of virtual education, particularly within fields necessitating hands-on experience. The VR application offers a standardized, accessible, and immersive means of learning, transcending geographical constraints. Its adaptability for future enhancements, such as task execution accuracy improvements and scoring system configuration, positions it as a dynamic and enduring solution within the domain of virtual education. The application's 90% accuracy in simulating these operations further underscores its efficacy and reliability.

Keywords: Virtual reality, virtual education, foundry, heat treatment.

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1. Introduction

With the shift in our society towards less physically proximate interactions due to the COVID-19 pandemic, an improvement in the virtual education medium is in high demand. This is even more so pronounced in subjects of teaching which require on-hands practice, demonstration, training, and skill evaluation which are not efficiently conveyed via traditional lectures through video conferences or pre-recorded videos. Another point of concern is for practices that require specialized equipment and skilled certified instructors to conduct a session. Accessibility in rural institutions is also a concern for practices that consume energy, material, or both to be conducted. Budgetary concerns may limit the accessibility of such institutions from providing adequate knowledge or in certain cases from providing that course at all. Subjects who deal in the operation of heavy machinery can also pose physical risks to the practitioners and their surroundings. Standardization of the contents taught is also an issue within the traditional education system in general. All the concerns raised thus far are present in the traditional Foundry and Heat Treatment process workshop sessions and exacerbated by the virtual class during the COVID-19 pandemic.

Virtual Reality is a type of extended reality (XR) technology that involves the fabrication or simulation of a three-dimensional space projected within a headset, isolated from the real world [1]. This allows the creation of content that is not possible to be conveyed via two-dimensional display screens. This enables the ability to fabricate, simulate, or mimic certain phenomena to the audiences while maintaining a high level of interactivity and realism which were usually greatly impaired within traditional media. These characteristics are advantageous in revolutionizing technology in various fields, such as the education industry, gaming industry, architecture industry, etc. With proper design, utilization, and integration, Virtual Reality technology can become an essential tool that propels our society toward a more efficient, accessible, and intuitive future. The extent to which the virtual world can be expanded and modified is infinite, providing the opportunity to present to the users rare or deleterious occurrences which may be deemed impossible in the real world. A common virtual reality system setup consists of the headset, the controllers, and a tracking sensor system. The headset, which is designed to be strapped onto the user's head, provides display outputs based on the rendered scenes. As opposed to the traditional display screen, a Virtual Reality headset also acts as a tracked viewport which adjusts the position and rotation of the rendered fields of view (FOV) depending on the user's head. The controllers, which usually consist of two hand-held devices, provide the user with a means of interacting with the virtual world, capturing, and simulating the movement of the user's hands and fingers [2]. The tracking sensor system provides the relational positioning of the headset and controllers and maps their movements within the real world onto the virtual world.

The virtual world simulated by the Virtual Reality system is rendered in real-time onto the headset device, providing instantaneous and life-like behaviors of the objects surrounding the scene [3]. This provides the perfect opportunity for designers to replicate and improve on certain aspects of traditional on-site education. As outlined above, traditional on-site education can be improved in many regards while the virtual education system lags it in many other aspects. Virtual Reality technology can rectify many, if not all these concerns.

The hands-on aspects of a manufacturing workshop consist of the demonstration, practice, and skill evaluation of the Foundry and Heat Treatment processes and are not able to be substituted with recorded videos of the process being performed. During the COVID-19 pandemic, health and safety measures prohibit on-site classes from being conducted which has greatly impaired the efficiency at which the workshop can be held; pre-recorded videos and lab handouts substituted for the traditional workshop sessions. This method is lacking in several regards, as students are limited by the footage recorded and are not able to view the process from different angles and are not able to test out or visualize different situations from the ones that are pre-recorded. As the workshop requires an extensive level of interaction to fulfill the objective of the workshopping sessions, only being shown pre-recorded videos or demonstrations is not effective in conveying the nuanced nature of the foundry and heat treatment process. Furthermore, skill evaluations are not able to be conducted, limiting the evaluation methods available to the teacher to quizzes and tests in theoretical knowledge [4].

The current virtual classes result in an ineffective transfer and retention of information due to the intrinsic limitation of online lecturing classes. To alleviate the issue, enhancing the ability to educate students in virtual classes is mandatory. Although there are many restrictions in a virtual class, its effectiveness can be increased using Virtual Reality technology to remove these constraints. While online classes can convey theoretical information as effectively as in-person lectures, on-hand classes are more nuanced. On-hand classes, such as the ones held for providing a demonstration of industrial and mechanical workshops, require students to participate in an evaluation and perform various tasks, which is nigh impossible with traditional online video classes. Using a foundry workshop as an example, an online workshop class would entail showing a pre-recorded video of the technician performing the tasks step-by-step, with intermittent additional commentary by the lecturer. There are 3 prominent issues that may arise from this teaching methodology. Firstly, the lecturer is not able to demonstrate the process to the students, should the students raise a question, the lecturer will not be able to demonstrate the answer by actual operation, but would need to rely on verbal communication. Secondly, the students are not able to view the demonstration from multiple angles, disabling them from thoroughly viewing the process through the view as pre-recorded, this restricts the students from getting multiple viewing angles of the same operation, which can greatly improve the understanding. Finally, the workshop will not be able to assess the development of the skills of the students in actual operation, leaving the assessor with only theoretical knowledge assessment. Should the content of the foundry workshop be translated into a Virtual Reality program, the lecturers will be able to standardize the content taught, and the students will be able to learn as effectively if not more than in an in-person workshop class. Hosting the class in Virtual Reality will allow the repeat of any processes that a student does not grasp totally as many times and from as many points of view as he or she wants. Students will also be able to practice the steps of the operation and take part in assessments which enable them to go through the steps and test their acquired knowledge.

Discounting the COVID-19 situation, the on-site methods of teaching still exhibit several fundamental flaws. Firstly, institutions with limited budgets, space, or both may not be equipped with the machinery and material required to conduct a workshop session. Secondly, despite having strict prohibitions and proper safety equipment, the foundry and heat treatment processes still expose the students to various health hazards. Thirdly, the lack of digitization of contents exposes the arts of manufacturing processes with a risk to the discontinuity of the know-how, given the nuanced nature of manufacturing equipment operation techniques. Finally, the hands-on nature of the workshop presents an issue in terms of repeatability. For instance, the number of times the process can be demonstrated may be limited, given a limited budget or material. In addition, the instructor may find it difficult to replicate certain phenomena every time the demonstration is conducted, this provides unequal information to the students [5].

2. Defining the Educational Challenges

2.1. Accessibility

With the current safety measures against the COVID-19 outbreak, on-site classes are not allowed; all classes are held online. Suppose the pandemic was to come to an end, it would still be necessary to prepare for a repeat of restrictions should a similar situation arise ever again. For lectures which focus on theoretical knowledge, accessibility is accommodated as there is no need for traveling. Demonstration classes, in contrast, are either cancelled or downgraded due to their accessibility tied to the on-site facilities. Usually, the demonstration class is there to support the theory class as it helps the learners to visualize how it's being done in real practice. To maximize the effectiveness of learning, an increase in the accessibility for the demonstration classes is mandatory. By combining the virtual world technology with the demonstration class, it significantly enhances accessibility and effectiveness as most of the restrictions are eliminated.

2.2. Cost-Effectiveness

Cost-effectiveness defines how far the experiment can be performed without exceeding the pre-defined budget. Due to the limited budget, the quantity and quality of the operation demonstrated are usually fewer and simpler than they should have been. The main reason for this is that on-site demonstration classes involving machines are likely to induce high costs. These incurred costs consist of machine costs, fixed costs, overhead costs, operating costs, material costs, etc.

With Virtual Reality technology, one does not need to be concerned with the cost incurred as the operations being performed in a virtual world are simulated graphically, allowing the user to utilize the objects, machines, and assets freely and infinitely.

2.3. Machine Operator Training

Each machine has its functionality and working procedures. To operate a machine effectively and safely, the operator is required to possess technical knowledge and follow standard safety instructions. However, this information and knowledge must be gained through training, where costs and time are invested. Without an expert in charge, the operation would end up suspended as leaving it to the amateurs might result in damaging the machine or causing danger to the attendees. Training is indeed crucial yet time-consuming, it's not wise to always train a new person if they are not guaranteed to always be the one who operates.

In a virtual world, the learners can get straight into the machine operation with only the tutorials provided. Without the need to be concerned about cost-effectiveness and safety, the learners will have the freedom to try out the operation the way they wanted and learn for themselves. Trials and errors are a part of the learning process for the learners to get accustomed to operating a machine effectively and enjoyably.

2.4. Repeatability

Repeatability is crucial in a learning process as it helps connect every piece of knowledge. By repeating the process, one can review and learn several times until they are confident and accustomed to it. However, in real practice, repeatability is unfortunately low due to the incurred costs and preparation time constraints. The lack of repeatability in the foundry workshop can greatly impair the ability to educate all students effectively. For instance, suppose a student was unable to notice a certain phenomenon during the workshop session, he or she would not be able to repeat the experiment and examine the mechanism that occurred that time, disabling the class from gaining insight into the principles surrounding the foundry process. These restrictions can be eliminated using Virtual Reality technology as it allows the learners to repeat the process unlimitedly.

2.5. Safety

Safety is one of the concerning factors when operating a machine. While measures in ensuring the safety of students, the surroundings, and machines are implemented strictly and to great effect, it is not possible to eliminate the intrinsic risk of danger to the operators and the immediate surrounding. This is especially apparent in the workshop surrounding the foundry process, which involves handling material at extremely high temperatures. While the instructors conducting the workshop session may be leading the workshop with utmost care and competence, it is not possible to assume that all students will always adhere to the protocol, intentionally or not. This may discourage instructors from allowing the students to independently conduct the workshop, which disallowed students from experimenting and reduced the effectiveness of the main goal of workshop class, which is to give students hands-on experience and insight in the process of interest.

3. Virtual Reality

Virtual Reality is a computer technology capable of creating a virtual world containing artificial objects and simulated environments. Systems with high processing power can simulate an interactive world for the user to experience. Most VR systems also allow the user to interact with the rendered 3D objects freely. In addition, the system can duplicate the phenomenon in the physical world by applying laws of physics to a simulated environment. In the virtual world, the user can freely navigate around within the defined bound of the environment. This allows the user to inspect and peruse the object of interest or a simulation of a phenomenon from all angles. This puts great emphasis on visual learning, which is one of the main mechanisms by which a person can learn new information.

Virtual Reality systems may vary in terms of philosophy and user input recognition method; from simple no input headset which is designed to strap smartphones with to dedicated sophisticated systems with state-of-the-art systems with high computational capacity and complex user input methods. With such a broad range of sophistication and availability in the market, it is crucial to specify the target range of Virtual Reality systems to support before the development of Virtual Reality software.

For Virtual Reality applications which require user interaction, the user input recognition capability of the system must allow for tracking of hand movement and basic finger functions. There are two main methods of capturing these inputs, controller-based and hand tracking systems [6]. The controller-based input system is when 2 joystick-like controllers are used to track the movement of the hand, with buttons located at different locations of the controller to emulate basic finger gestures. The hand tracking system utilizes computer vision within the Virtual Reality system kit to track and capture the three-dimensional movement of the hand, as well as recognize any finger gestures. While hand tracking system allows the user to utilize the Virtual Reality headset hands-free, the computational overhead required for the system to utilize computer vision, object detection, and segmentation, as well as recognize hand gestures in real-time may restrict the usage of such features for more simple applications which do not require great computing power. It is therefore advisable. A study comparing the usability and interaction time of controller-based input and hand-tracking systems has shown that hand-tracking systems are still not as intuitive to use compared to the traditional controller-based variant.

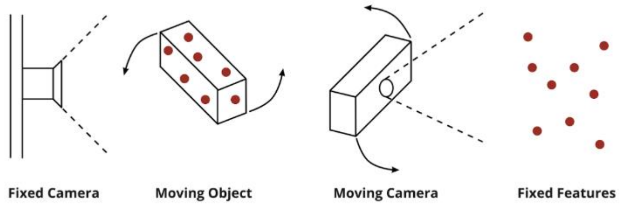

Fig. 1. Conceptual differences between (left) outside-in tracking system (right) inside-out tracking system.

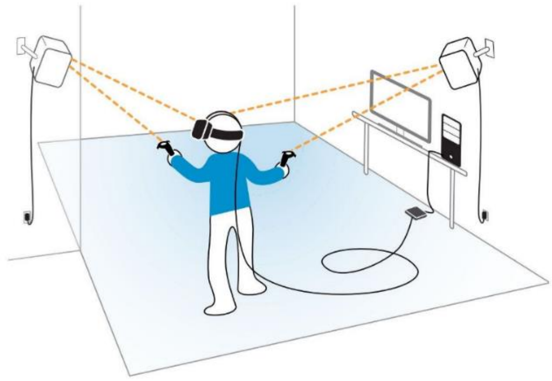

Fig. 2. Typical set-up of hardware for outside-in tracking system for a Virtual Reality system. [7]

The positioning and the orientation of the user's head is usually tracked and mapped with the help of the headset, which is strapped on the head. There are currently two main philosophies of tracking the headset, outside-in and inside-out tracking systems, as shown in Fig. 1. Inside-out tracking is a system of tracking used by the first few generations of modern Virtual Reality systems, such as the HTC VIVE and Oculus Rift. Outside-in tracking utilizes multiple external "base stations" mounted on stationary objects which captures the movement of the headset and the controllers. The inside-out tracking is a system of tracking used by more recent generations of modern Virtual Reality systems, such as the HTC VIVE COSMOS and Oculus Quest. Inside-out tracking utilizes multiple camera sensors mounted on the headset itself, which then maps the perceived movement of surrounding stationary objects to calculate the movement of the headset itself, once the spatial relation is established, the system is then able to compute the movement of the controllers and any other accessories.

In the context of modern education, the integration of Virtual Reality systems opens exciting possibilities for virtual education and online learning, transcending the limitations of traditional teaching methods. Virtual education is an approach in transferring information and knowledge without restricting the learner in place and time [8]. In the modern era, virtual education is often referred to as online learning. With the technological advancements available, learners can study entirely online; this adds convenience to the learners' accessibility as there are fewer restrictions. Traditional Virtual Reality systems also ship with the controller, and in some cases, support hand tracking, both of which support the emphasis of Virtual Reality systems on user interaction. This enables the Virtual Reality media to be designed around maximizing user interaction and promoting self-learning experience, which has demonstrably shown the highest information retention. This will promote the efficiency by which students are able to conduct remote education. While the necessity of interaction of virtual education is mostly limited to subjects with extensive hands-on education, developing a baseline by which education media can be developed for the Virtual Reality systems can be beneficial in safeguarding the education system from further disruptions from any future events that prohibit or limit the accessibility of students from on-site learning [9].

4. Foundry and Heat Treatment Processes in Industrial Manufacturing

4.1. Foundry Process

Foundry is a process where castings are being produced by either melting ferrous or non-ferrous materials [10]. The process can be subdivided into two major parts: Mold Creation and Casting; each part consists of multiple processes within. An overview of the process flow is as illustrated in Fig. 3.

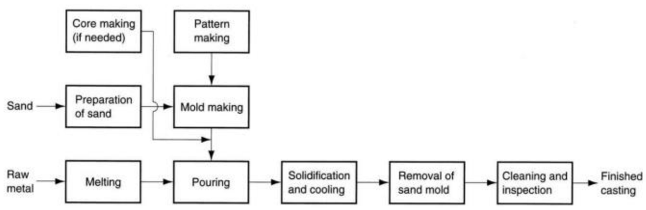

Fig. 3. Process flow of the sand casting (Foundry Process). [11]

Mold creation, usually sand mold, is the first and crucial step of the Foundry process as it dictates how the shape of a final product will be formed and structured. In this initial stage, the mold making stage requires a preparation of sand, pattern making, and core making (if needed). A finished part or a prototype model is used for forming the shape of the castings, while the core forms as the inner cavity of the castings. The finished part is then laid in a box which will undergo the processes of sand filling and compaction to create a mold sandbox, consisting of two surface contours of the upper part and bottom part of the model. During this process, the sand mold has a gating system setup which allows the molten material to be poured in. The core, which is used for forming the inner chamber, is created using a core box. With all the preparations set in place, the mold can be assembled.

The casting process starts with melting the material. Normally, the material used in casting is ferrous material. During the process of melting, the material is placed in a crucible which is then placed in a furnace for melting down the material. Each of the materials has its own melting point; thus, the temperature and time used in the process depends on the material's properties. For a conventional process of melting the material, the operator needs to circle the crucible over the flame for constant heating. Once the material has been molten completely, the molten material is then poured into the mold through the pouring cup (gating system). The liquid flows into the mold and fills up the space inside the sand mold. After a certain period, the liquid is solidified and cooled down, forming a solid casting. After the casting part has cooled down, the casting parts are separated from the sand and sandbox as part of the removal of the sand mold process. The casting parts then undergone the cleaning process and inspection as part of the final process [11].

4.2. Heat Treatment Process

Heat treatment is a process of heating metal without reaching the melting point then cooling the metal to make it stronger or more malleable. The process can be subdivided into three major stages: Heating Stage, Soaking Stage, and Cooling Stage. An overview of the process flow is illustrated in Fig. 4.

Fig. 4. Process flow of heat treatment.

During the heating stage, the metal is undergoing a heating process. The main objective of this stage is to heat the metal uniformly. Heating the metal unevenly may result in a distorted or cracked section of the metal due to some sections of the metal might expand faster. The heating rate and condition depend on the heat conductivity of the metal, the condition of the metal, size of the metal, and cross-section of the metal. For larger parts or parts with uneven cross sections require a slower heating process than small parts to allow the temperature of the inside close to the surface temperature, preventing the risk of cracking.

In the soaking stage, the purpose of this stage is to preserve the metal at the appropriate temperature until the desired internal structure takes shape. The metal undergoes soaking for a certain length of time, often called the soaking period. The timeframe of the soaking period is determined based on the chemical analysis and mass of metal. As for uneven cross-sections metal, the soaking period is determined based on the largest section.

For the final stage, the cooling stage, the metal is cooled back down to room temperature. The method used in the cooling stage depends on the type of metal. Some may need a cooling medium, a gas, a liquid, a solid, or a combination of multiple mediums. The cooling rate depends on the metal's properties and the medium for cooling. Usually, the rate of cooling is determined based on the essential factors in the desired properties of the metal [12, 13].

4.3. Storyboarding

Following the examination of various aspects of the foundry and heat treatment processes, the following section will delve into how these processes are translated into a well-structured storyboard for the VR application. The entire process aims to create a gear-shaped workpiece (Fig. 5) from aluminium scraps.

Fig. 5. 3D model of the gear workpiece.

The VR application takes a structured approach to the complex Foundry and Heat Treatment processes by dividing them into four distinct stations. In the Foundry process, the Molding Station (Table 1) and the Furnace Station (Table 2) stand out as critical segments where users receive step-by-step guidance to grasp the intricacies of these operations. The inclusion of the Workbench Station (Table 3) serves as a vital link in simulating the task of trimming unnecessary components from the gear workpiece, seamlessly connecting the preceding stations. The Heat Treatment process is comprehensively covered through the Heat Treatment Station (Table 4).

Table 1. Execution steps in the molding station.

Step	Execution
0	Navigate to the Molding Station.
1	Interact with the Gear Tool to place it in the molding box.
2	Interact with the Sandbag to fill the molding box with sand.
3	Interact with the Steel Trowel to smoothen the sand surface.
4	Interact with the Sprue and Runner Tool to insert them into the molding box.
5	Interact with the Top Box Tool to put it on top of the molding box.
6	Interact with the Riser Tool to place it in the molding box.
7	Interact with the Sandbag to fill the molding box with sand.
8	Interact with the Steel Trowel to smoothen the sand surface.
9	Interact with the Molding Box to remove the Sprue and Riser Tools.
10	Interact with the Slick to form a pouring basin.
11	Interact with the Vent Rod to create channels for letting excess gas escape.
12	Interact with the Molding Box to remove the top molding box.
13	Interact with the Molding Box to remove the Gear and Runner Tools.
14	Interact with the Molding Box to put the top molding box on top of the bottom molding box.
15	Interact with the Molding Box to move the molding box to the Furnace Station.

Table 2. Execution steps in the furnace station.

Step	Execution
0	Navigate to the Furnace Station.
1	Press the Power Button on the power generator.
2	Interact with the Aluminum Scraps to fill the furnace.
3	Interact with the Temperature Control Panel to adjust the temperature.
4	Interact with the Furnace Wheel to pour the molten Aluminum into the crucible.
5	Interact with the Crucible with Tong to pour the molten Aluminum into the molding box.
6	Interact with the Molding Box to extract the gear piece and move to the Workbench Station.

Table 3. Execution steps in the workbench station.

Step	Execution
0	Navigate to the Workbench Station.
1	Interact with the Circular Saw to trim the gear.
2	Interact with Gear Piece to move to the Heat Treatment Station.

Table 4. Execution steps in the heat treatment station.

Step	Execution
0	Navigate to the Heat Treatment Station.
1	Interact with the Furnace Handle to open the furnace lid.
2	Interact with the Tray and Gear to move them into the furnace.
3	Wait for the process to complete.
4	Interact with the Furnace Handle to open and remove the gear piece into the Bucket of Water.
5	Wait for the process to complete.
6	Interact with the Bucket of Water to remove the gear piece.

5. Virtual Reality Development

The development process of VR software is similar to other software development procedures. The first step among all is the design phase. However, for certain purposes, this step can be skipped as the developers can import assets from the community-run libraries. There are downloadable contents, such as backgrounds, textures, and 3D models, available online. Even though there is free content available, the quality of the object might not be as desired; 3D modeling is obligatory for customized experiences. The second step is to determine which type of VR platform (SDK) the application will be centered around. Each of the platforms has different APIs and tools available for use; therefore, the decision made in this step is crucial whether which of the following will suit you the most [14].

With all the above preparations ready, the assets will be imported to the software development engine of choice. To allow interactions between objects, scenes, or environments, they will be assigned properties that define what and how their interaction would be. In addition, animations can be added to the existing object to visualize actions as pre-defined. Certain objects' behaviors or interactions might require scripting. Scripting is a script (or a piece of code) that informs the system how the object will interact when a certain condition is met. Normally, customization of the script requires programming knowledge, which means the more complex the behavior is, the harder for the algorithms to be implemented [15].

5.1. Unity Engine

Unity is a cross-platform game engine software capable of developing two-dimensional (2D) and three-dimensional (3D) interactive simulations. This engine supports a variety of platforms, such as desktop, mobile, console, and Virtual Reality platforms. As a game simulation engine, the developers are provided with features to modify laws of physics, 3D rendering, and collision detection between objects [16]. Furthermore, the assets created are scalable and reusable, making a development process much easier. With its capabilities, this engine has been utilized in many industries and different purposes; for instance, the automotive industry tests an effect of aerodynamics on their latest prototype, the architecture industry simulates a virtual house model tour to their clients, etc. To give Unity instructions, a programming language, C#, is used to communicate through interactive algorithms called scripts. With proper programming knowledge, one can maximize the ability to freely construct their virtual world effectively.

5.2. 3D Modeling Process

3D Modelling is a fundamental step for creating a virtual world as it will be used in rendering artificial objects and environments in the scene. Without 3D Modelling, an occurrence of interaction between objects in the virtual world is nigh impossible if the properties or behaviors are yet to be applied to the existing objects. The process of creating 3D models requires CAD software in doing so. There are several choices for modeling software that has high compatibility with Unity Engine; for example, Autodesk MAYA, 3DS Max, Blender, SketchUp, and ZBrush. In this development plan, Blender and Unity are the main software used for creating 3D objects and assets for virtual world creation.

The method of creating 3D models can be done in various ways. The suitable method for this research would be box modeling where the modeling technique starts from a simple shape (such as cube, cylinder, or sphere) and expands further until the final shape is complete. Since the objects in the Foundry process and Heat Treatment process are not complex shapes, the box modeling method provides a fast and straightforward way to achieve the final model. For example, for a crucible in the Foundry process, a cylinder can be used as a starting shape for the modeling process.

Once the model is constructed, prior to the texturing process, the model will undergo a retopology process where the number of polygons of the model will be reduced as an optimization process. Once the model has been retopologized, the texturing process will now begin. Similar to the 3D models and assets, textures can be downloaded online if they are available; otherwise, the texture needs to be created manually using other software. Applying the texture to the 3D model requires several preparation steps. First, the UV mapping and unwrapping processes allow projecting and mapping a

3D model to a 2D image, providing smooth and accurate texturing. If the object is designed to be animated, rigging and skinning processes are required to ensure smooth connectivity of the texture on the 3D model when animating. Rigging is a process where digital bone structures are added to the 3D model to allow mobility, while skinning is a process where mesh binding is performed to improve the smoothness of the model texturing. Upon completing the necessary preparations, the next step is to apply textures to the 3D model. There are various approaches to texturing, and one of the commonly used methods is normal mapping. Normal mapping is favored for its accessibility and effectiveness in enhancing the visual quality of 3D models. Software engines like Unity offer integrated tools to facilitate the automatic application of normal maps to objects. These normal maps, which are often accessible online, introduce intricate surface details, such as bumps and crevices, without introducing additional geometric complexity.

In simpler terms, normal mapping is a technique that utilizes a texture to mimic the appearance of fine surface details and lighting effects on a 3D model. It elevates the realism of the object without necessitating a more complex geometric structure [17]. Once the texturing process is complete, whether through normal mapping or alternative methods, the object is considered finalized and ready for seamless integration into virtual environments [18]. Unity, known for its versatility as a game engine, supports an array of 3D file formats, including .FBX, .dae (Collada), .dxf, and .obj files [19]. Consequently, the fully textured 3D assets must be exported in a compatible format for effortless integration into the Unity Engine.

5.3. Virtual Reality Software Development Framework

Unity is a 2D/3D game engine software with built-in features available for the developers to create a game, simulation, rendered object, mobile application, or AR/VR application. The Unity engine provides specific tools for performing certain features, such as modifying properties, simulating scenes, and navigating through the available assets. These features can be accessed from the main interface. In Fig. 6, the illustration represents the Unity's interface where;

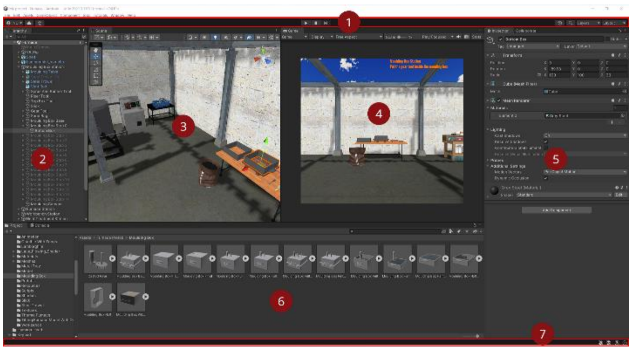

Fig. 6. Unity's Interface.

Table 5. Unity's interface descriptions.

#	Item	Description
1	Toolbar	Provide access to the most essential working feature.
2	Hierarchy Window	A hierarchical text representation of every object in the scene. Each object in the scene is linked with the hierarchy list
3	Scene View	Provide the ability to visually navigate and edit the scene. This can be viewed in a 2D or 3D perspective, depending on the goal.
4	Game View	Visualize a simulation of the final rendered scene which is displayed through the scene cameras. When the play button is clicked, the simulation begins.
5	Inspector Window	Provide the ability to view and edit all the properties of the currently selected object. Different types of an object may have different sets of properties, the layout and contents of the inspector window vary depending on the object type.
6	Project Window	Display the library of assets that are available for use in the current project. Imported assets can be accessed here.
7	Status Bar	Provide notifications regarding the Unity processes, and quick navigation to related tools and settings.

The general ability of the game engine is a feature capable of adding and modifying physics, collision detection, object interaction, and properties of artificial objects and scenes. For example, the image shown in Fig. 7 is a global setting for 3D physics. In this setting, the developer can modify several factors, such as world gravity (which is set to -9.81 m/s2 in the y-direction as a default) which applies gravity to all rigid body components, bounce threshold which limits bouncing action for two colliding objects if their relative velocity is below the designated value, etc. Similarly, each object or component in the scene has its own properties which can be modified independently from each other [20, 21].

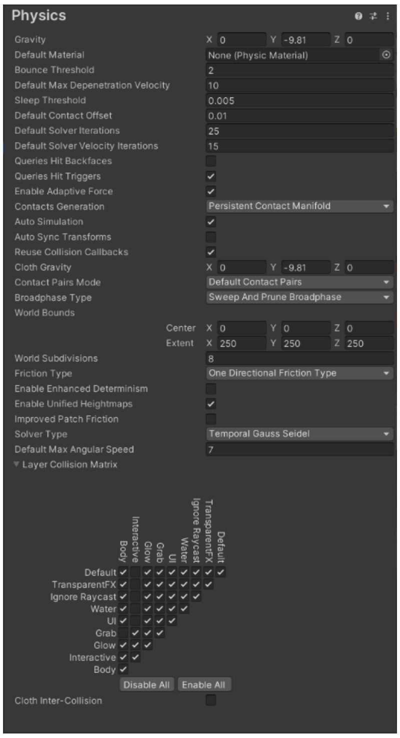

Fig. 7. Global settings for 3D Physics.

With each object assigned with properties, the next step is to set their collider boundary. This boundary allows the system to detect when two objects are interacting or colliding with each other. There are multiple types of colliders as listed in Fig. 8. Each of the colliders has a different computational capacity and boundary shape. In Fig. 9, the illustration shows different types of a collider added to the gear object. The box collider adds a bounding box of a box shape, a sphere shape for a sphere collider, and a capsule shape for a capsule collider. The bounding boxes are used for collision detection. When applying the colliders, the collision is handled automatically, with the collider calculating which section of the bounding box was intercepted with and controlling its reaction between the object(s) that it collided with.

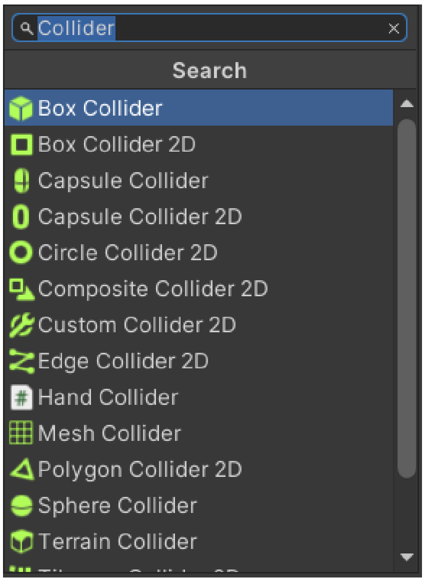

Fig. 8. List of Physics colliders provided in Unity.

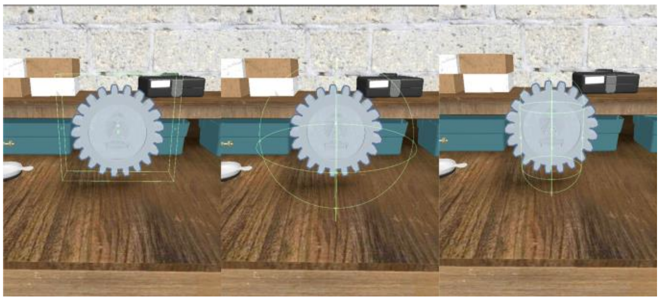
Fig. 9. Different types of colliders applied to the gear object.

The colliders are there to support the realises of the virtual world; for example, adding collisions to make objects collide with each other and bounce away, prevent an object or a person passing through a supposed-to-be rigid body, etc. The collider features can be expanded further once they get into a more complex mechanism.

Unity provides an ability to create a devoted script for performing certain actions. The Unity script supports several programming languages, such as JavaScript, C#, and a form of Python - Boo. All three are equally fast and can interoperate. In order to utilize scripting to its full potential, a good understanding of programming is required. The script opens a freedom in creating a desired interaction or feature to apply to a certain scenario or object. For example, execute a set of animations once a certain object or button has been interacted with, provide a physics simulation of a real-world phenomenon, etc. However, whether the scripted behaviour is executed as intended in any scenario or not is depending on the level of algorithms implemented.

Normally, the scene or simulation implemented in the game engine is visually displayed on the computer's screen like most software, video games, or web applications. To interoperate with the VR headset and visualize the scene in a form of Virtual Reality, additional plug-in framework is required in doing so. Unity has developed a new plug-in framework called XR SDK that allows integrating the Unity engine with the XR providers, supporting a full use of its features. To configure the Unity project for XR technology, XR plug-in management needs to be installed; this allows access to a configuration of XR features, such as setting up camera tracking of the VR headset. This integration process is mandatory as it is required for connecting the created scene and interaction with the VR devices [22].

5.4. Scene Development and Configuration

To simulate an accurate representation of the virtual world as prescribed by the conceptual design and the requirement analysis, the 3D assets created previously must be assembled into its respective location and function. Speaking in general terms, the virtual world of the software may either strive to either replicate a real-world setting or create a fictional setting altogether. The development and configuration of the scene involves aggregating the assets together into a coherent scene which will function as the setting in which the users will explore and interact with the world. The tasks related include configuring the physical properties of each entity, as well as creating and applying the appropriate texture onto each entity to achieve the visual as intended by the developer. The 3D objects in the scene can be configured independently; for example, add a collision detection (collider) to an object that detects inter-collision between two or more objects and responses as prescribed, configure a bounciness of a certain type of material, configure an object's material and weight, etc. The configuration for each object is the final touch of the scene creation which makes the objects realistic and interactable.

For the Molding Station (Fig. 10), the related 3D models are imported and configured to replicate the real-world environment. Similarly, the Furnace Station (Fig. 11), Workbench Station (Fig. 12), and Heat Treatment Station (Fig. 13) will contain the necessary components for the entire process. The scene construction can be done by importing the objects and designating the placement and orientation of the objects. Once the scene for each station is ready, the imported objects are assigned the appropriate properties and are configured with bespoke functions which will allow them to perform their respective purposes within the simulation. For example, the furnace shall be hooked to the furnace wheel which must be interactable and correspond to the action of the user's input. The state of the furnace wheel shall then be reflected in the rotation of the furnace itself. Each of the actions that the user is supposed to perform will have an instruction or tutorial explaining the process beforehand for the user to perform the task accurately and gain an understanding of the reasoning behind each action or task. The scene setups, scene transitions, object interactions, instructions, tutorials, and tasks to perform will follow the storyboard planned in the previous section.

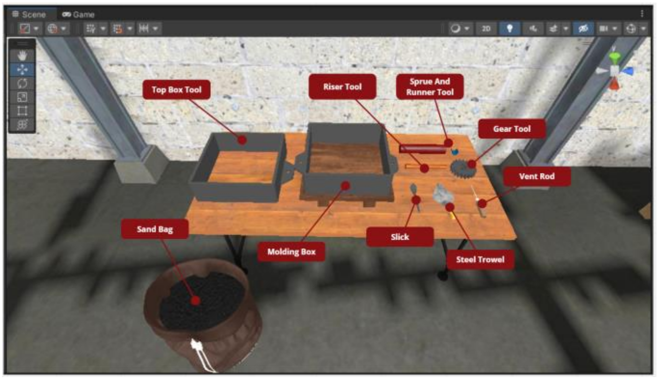

Fig. 10. Molding Station.

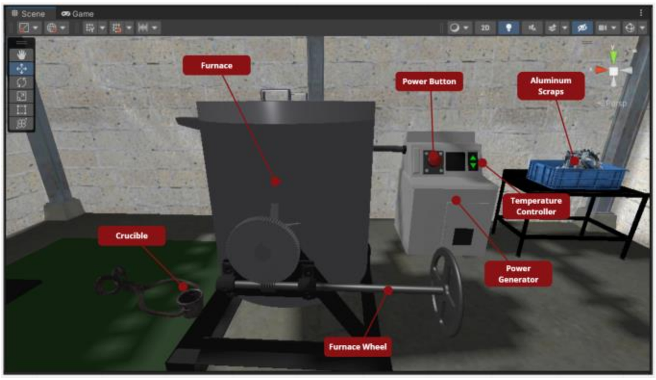

Fig. 11. Furnace Station.

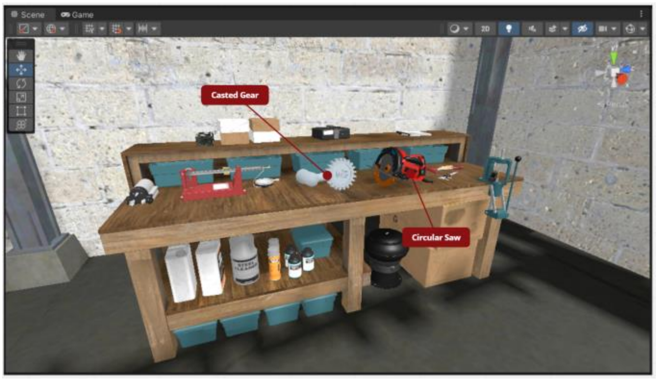

Fig. 12. Workbench Station.

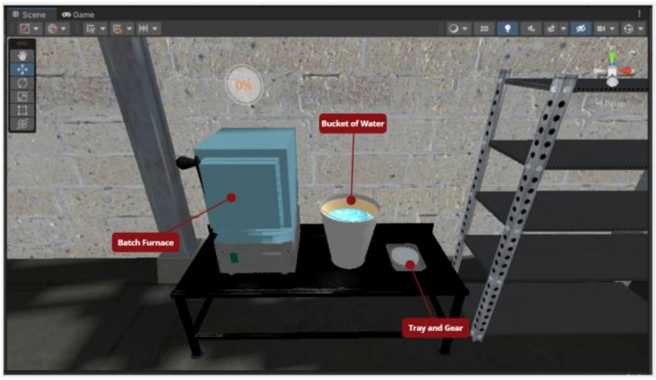

Fig. 13. Heat Treatment Station.

5.5. Application-Specific Script Development

Once the basic physics properties are set up and implemented, the developer must then create the main functionality of the application, the business logic function. This will require the developer to design and code C# functions which will drive the flow of the application, simulate the necessary physics surrounding the processes, and outline the interactions the user will have with the application. The input aspects of the application, the user input available for the user, will need to be designed carefully to fulfill the required interactions. The output presented to the user, meanwhile, needs to balance between responsiveness and accuracy. While a complex simulation of physics is desired for the correct representation of the elements, certain rendering techniques may be preferred due to their simplicity and reduced computational requirement.

In the Foundry Lab Scene, the user spawns at the center of the scene with hand models representing VR controllers in the real world. The scene has been set up with several stations, such as Molding Station, Furnace Station, Workbench Station, and Heat Treatment Station. As each station was set up in different locations in the scene, the user must move to each station virtually. To achieve this, teleport is the transportation means that allows the user to utilize the VR controllers to move from one place to another. By simply adding a Teleportation Area component (Components available from the XR Interaction Toolkit) to the scene and configuring minor adjustments, the user gains the ability to move around. To visualize the crosshair and location where the teleportation will end up, adding a teleporting ray to both hands aid in visualizing; this can be achieved via the built-in XR Ray Interactor component.

At the Molding Station (Fig. 10), the user is tasked to prepare a molding box for the next station. The process involves simulating each step of making the molding box which requires the object interactions. Once the user interacts with the specific objects in the scenes, specific actions will be triggered through a script. For example, when interacting with the Gear Tool, the Gear Tool is relocated to the center of the molding box which marks completing the first step. The interaction can be detected from the collision made between the user's indicator ray and the object's collider. Based on the interaction detection, the object must include a collider as well as a component called XR Simple Interactable. The XR Simple Interactable allows the system to trigger a specific script based on the event invoked. For instance, when the user interacts with the Gear Tool, this invokes a Select Entered event which calls a script to relocate the Gear Tool into the molding box while also checking whether the user is executing the correct step or not; otherwise, the score will be deducted accordingly. The same procedure applies to the remaining steps for the Molding Station. Furthermore, the step progression has been tracked internally which renders the instructions progressively (only in Training mode).

At the Furnace Station (Fig. 11), the user is tasked to power the furnace to pour molten Aluminum into the molding box, forming a cast gear piece. The station involves interaction with several objects in order. The furnace is powered by the power generator which requires the user to use their hands to press the power button. This action is simulated and detected using the hand model's collider and the power button's collider. Once the two colliders make contact, several scripts and actions are triggered, such as updating the parameter to inform other scripts that the furnace has been turned on, playing the furnace sound, rendering the power generator's display screen, etc. The power generator has a temperature controller that the user can interact with to adjust the heating temperature (an incorrect temperature range will affect the scoring). Once all the requirements are met, the system will allow the user to pour the molten Aluminum into the crucible when interacting with the furnace wheel. By interacting with the furnace wheel, it then rotates the furnace in response. Once the furnace reaches the pre-defined rotation angle threshold, the system will then render the pouring animation of molten Aluminum accordingly. With a similar flow of progression, the crucible can be interacted with once it is filled with molten Aluminum. The system then triggers the animation of pouring the molten Aluminum from the crucible to the molding box. Later, the user can extract the cast gear piece from the molding box, marking the end of the Furnace Station.

At the Workbench Station (Fig. 12), the user is tasked to trim the gear using the circular saw in preparation for the Heat Treatment Station. The same procedure in which the interaction triggers a certain event that calls different scripts is applied as the main logic.

At the Heat Treatment Station (Fig. 13), the user is tasked with heat treating the workpiece. The same procedure is applied in this station similar to other stations. However, new characteristics have been introduced in this station to simulate different actions. The furnace has a handle that simulates opening/closing the furnace lid which has a specified script to keep track of whether the furnace lid is currently open or closed as well as to check if there is a workpiece inside before starting the heating process. The heating process is controlled by the progress indicator which reflects how the workpiece is being heated over time. The progress indicator updates constantly at runtime script which is done in the background as time goes on. If the user decides to open the furnace lid arbitrarily without waiting for the heating process to complete properly, this affects the workpiece's quality and the user's score. The same process applies to the quenching process.

Once all the stations have been completed (internally tracked the progression), the system displays a UI overlay on the screen to inform the user of lab completion and their score tracked throughout the progression. In the Exam mode, upon completion, the system triggers the API call via script to update the score received to the corresponding student record. Once all the post-processes are complete, the user will be navigated back to the Lab Selection Scene.

6. Salesforce Integration

6.1. Data Management

Salesforce is a strong and adaptable tool in the world of data management. Salesforce's sophisticated CRM (Customer Relationship Management) system, which enables users to effectively manage enormous volumes of data, is one of its key assets. Structured data organization serves as the framework upon which this system is created, with objects acting as tables and fields as table columns. Due to the logical organization of the material as a result, it is easier to access and understand. Salesforce supports a strong data model as well. It provides Standard, Custom, and External object types. Standard objects, including Account and Contact, are prebuilt objects that Salesforce offers. On the other hand, users can design new objects to fulfil requirements, which increases the level of customization. Salesforce can interface with external data sources thanks to external objects, showcasing its system interoperability [23].

Salesforce's security and sharing settings are another distinguishing characteristic in the field of data management. Salesforce places a high priority on data security and offers users fine-grained control over who can access and modify data. It has many data access levels, including Organization-wide defaults, Role Hierarchies, Sharing Rules, and Manual Sharing, to guarantee that only authorized individuals can access sensitive data [24]. Additionally, Salesforce offers a vast array of data management capabilities. For instance, the Data Import Wizard and Data Loader, which enable the management of big datasets. Numerous third-party apps are available on Salesforce's AppExchange to expand its functionality.

For effective data management, Salesforce provides a comprehensive, secure, and highly adaptable platform. Many businesses and research initiatives find it to be an enticing option because of its organized approach to data organization and strong data management features.

6.2. Open Authorization

Through the use of C# programming in Unity, Salesforce was integrated into the Virtual Reality application. We were able to create solid links between the VR environment and Salesforce's cloud-based database services due to this potent object-oriented language. The recording and monitoring of user performance indicators in the Exam mode was explicitly addressed by the C# scripts that were written to handle data sharing. These scripts use the Salesforce API (Authorization Through Connected Apps and OAuth 2.0) to communicate user performance data from the Unity application to Salesforce, where it is organized and securely stored for further retrieval and analysis. The VR application can manage connections with the Salesforce API using Connected Apps from Salesforce and OAuth 2.0 authorization. The external application can safely integrate with Salesforce using a technology called Connected Apps. Contrarily, OAuth 2.0 is a mechanism that enables the VR application to obtain authorization to access Salesforce resources without the need to divulge private user information [25].

OAuth 2.0 Client Credentials are used Salesforce must be configured with a Connected App before using Flow. To put it simply, this entails defining the VR application within Salesforce's system in a way that the latter will recognize and allow data interchange between the two. Setting various parameters, such as the API (Enable OAuth Settings) and the OAuth Scopes (Access and control your data (API)), is part of the simplified process of configuring a connected app [26]. Once the Connected App is configured, it provides us with a Consumer Key and Consumer Secret, akin to a username and password for the application. With these credentials and the OAuth 2.0 Client Credentials Flow, the VR application can authenticate itself directly to Salesforce's API, facilitating a secure exchange of data. This robust mechanism underscores the strength of Salesforce's integration, enabling safe, efficient, and secure data management in the VR application. The VR program has been improved by this integration, which has expanded its potential uses in the field of virtual education by transforming it into both an effective data management system and an educational and evaluation tool.

6.3. System Architecture

The Salesforce system architecture is based on a fundamental structure consisting of objects, fields, and records. Within this framework, objects serve as containers, similar to database tables, where specific datasets are stored. Fields, on the other hand, resemble columns in these tables, representing individual pieces of data associated with a given object. This interplay between objects and fields forms a systematic foundation for storing and managing data within the Salesforce platform.

Delving further into the integration of the VR application with Salesforce, the architectural framework plays a central role. To illustrate, let's take the example of students, likening them to objects, and their names and identification numbers as fields. In this context, objects function as containers for student data, similar to how database tables hold specific datasets. This setup closely resembles the conventional database table structure, where each row corresponds to individual data entries. Fields, much like columns in a table, represent distinct data attributes, including a student's, student ID, student’s academic year, and their scores (Fig. 14).

This architectural framework is also highly adaptable, allowing for tailored configurations to meet specific needs. For instance, a custom object called Score__c (where __c designates a custom object or field) can be introduced to monitor new score instances generated by the VR application. Furthermore, the VR application utilizes a framework known as connected apps to streamline the connection between an external application, specifically the VR application, and Salesforce. This connection is facilitated through Salesforce's Identity and Data APIs, supported by a consumer key and consumer secret, both generated during the setup process. These sophisticated architectural elements empower the VR application to effectively access and manage data within Salesforce as required, establishing the foundation for its seamless integration with the Salesforce platform.

Fig. 14. Student records list view in Salesforce.

6.4. Data Loader

The Salesforce Data Loader is a flexible solution that has many benefits for managing data inside the VR application. Data Loader is a standalone application that enables us to connect with Salesforce data by offering functions like record insert, update, deletion, and export [27]. When managing enormous amounts of user performance data from the VR application, this capability shows to be essential.

In its practical application, this feature empowers instructors to proactively prepare a list of students for the course using a CSV template (Fig. 15). The instructors can enter the necessary student details into the template and subsequently upload this prepared CSV file directly into Salesforce using the Data Loader. The Data Loader's user-friendly mapping tool enables the alignment of CSV columns to the respective Salesforce fields, guaranteeing the precise assignment of each piece of student data. The data is then uploaded to Salesforce, where it is safely kept, through the Data Loader (Fig. 16). This procedure offers an admirably simple method for maintaining a wide range of data, from initial course setup to dynamic student assessment records.

Salesforce and the VR application work together to achieve more than just maximizing the potential of a powerful CRM system. The promise of effective, dependable, and scalable data management is encapsulated in it. This not only improves the operation of the VR application but also vastly increases its potential use-cases, making it an even more potent instrument for virtual education.

	A	B	C	D	E	F	G	H
1	Name	Student_Name__c	Student_ID__c	Password__c	Semester__c	Academic_Year__c	Phone	Email__c
2	Naris Lawankowit	Naris Lawankowit	6370144721	12345	2	2023	0888888888	6370144721@student.chula.ac.th

Fig. 15. Student CSV Template for uploading student records to Salesforce (green fields are required and gray fields are optional).

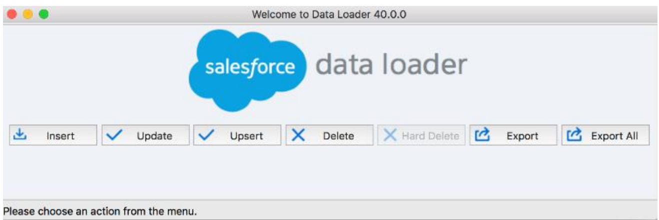

Fig. 16. Data Loader.

6.5. Record-Triggered Flow

As the VR application is now connected to Salesforce, we can enhance the system to automatically produce reports outlining student involvement and assessment results from their actions in the VR environment due to Salesforce's powerful automation features. These reports are created and immediately forwarded to the instructor's email, enabling prompt review and assessment.

The process of setting up a Record-Triggered flow to send out an email to an instructor when a student's score has been updated commences with the Salesforce home screen. Prior to setting up the record-triggered flow and adding the send email feature to the flow, two configurations must be set up for reference. First, the email template must be established; this can be set up in the Email Template Settings (Fig. 17). Here, the email template consists mainly of the email subject and body. With the built-in feature of referencing fields in the Salesforce database, the email template itself inherits the ability to refer to the student's record fields (a.k.a. Merge Fields), such as Student ID, Student Name, Foundry Score, etc. For instance, the Student ID is stored in an object called Account and the field within Account object is called Student_ID__c. Hence, a dynamic reference can be inserted into the email template as such {!Account.Student_ID__c}. Later, the email template will be referencing to the student record which will populate these Merge Fields with the correct values from the record itself before sending out the email to the instructor(s). After the email template has been set up properly, the last configuration required is the Email Alert. This can be configured in the Email Alert Settings (Fig. 18) which later will be referenced in the Record-Triggered flow process by the send email element. This Email Alert allows us to pre-define the email recipients from the User records or additional email addresses (up to five) as well as link the email template created beforehand.

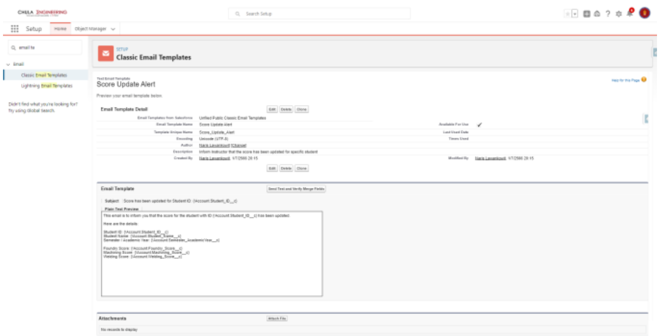

Fig. 17. Email Template Settings.

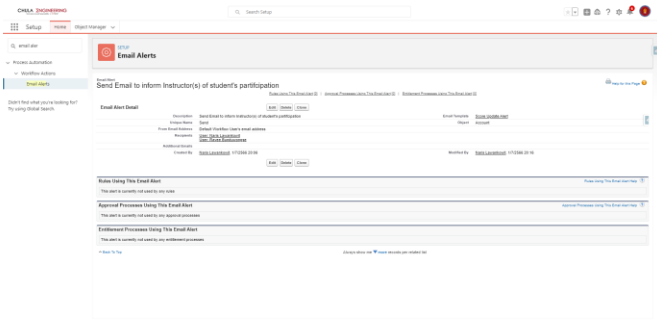

Fig. 18. Email Alert Settings.

After the two dependencies have been sorted out, the record-triggered flow is now ready to be set up. In the 'Flows' section, by clicking on 'New Flow' followed by the selection of 'Record-Triggered Flow', it will prompt you to fill in the pre-configuration (Fig. 19). Since the main objective here is to capture the score updated to the student record, the system will need to track from the score fields whenever there is an update to any of the following fields: Foundry_Score__c, Machining_Score__c, or Welding_Score__c under the Student object (Account object as the API name). Thus, the pre-configuration would be established as follows: Student as the Object, a record is updated as the Configuration Trigger, and Is Changed for the Foundry_Score__c, Machining_Score__c, or Welding_Score__c equal to TRUE as the Set Entry Conditions. For the rest of the configuration, they can be left as is. The next step is to add the Send Email Alert element to the flow which requires you to set the Record ID. Here, {!$Record.Id} is set for the Record ID field to reference each of the student's records itself (Fig. 20). Once done, we can now click on the Activate button to make the flow active and ready to be used (Fig. 21). Upon this, making changes to the score fields in the student's record triggers the flow instance which then sends the email containing the student's details and scores to the pre-defined email addresses (Fig. 22).

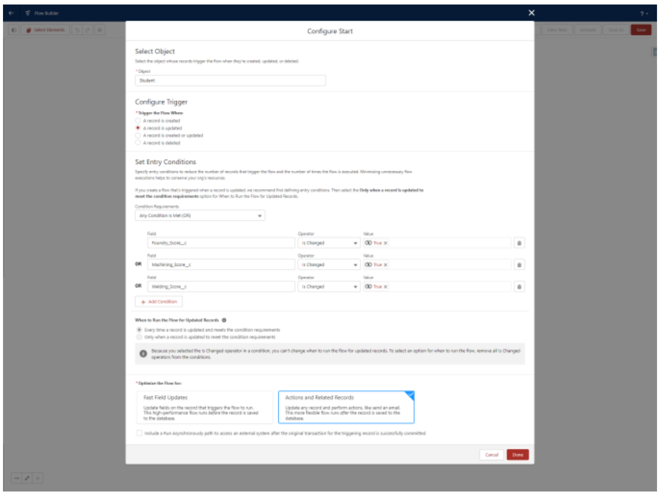

Fig. 19. Record-Triggered Flow Configuration.

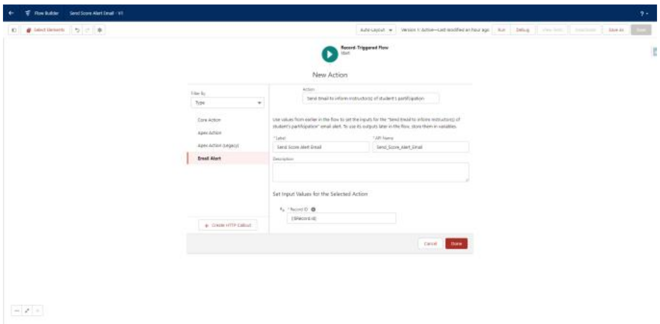

Fig. 20. Email Alert Element Configuration.

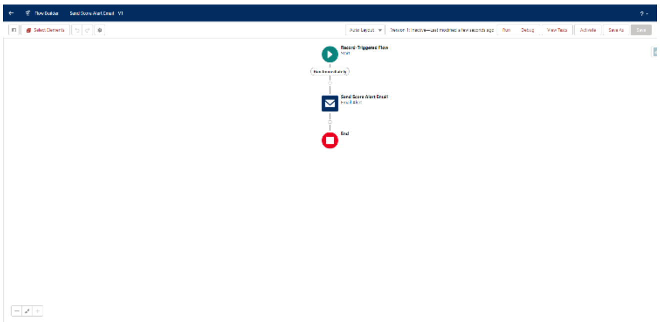

Fig. 21. Record-Triggered Flow with Send Email Feature.

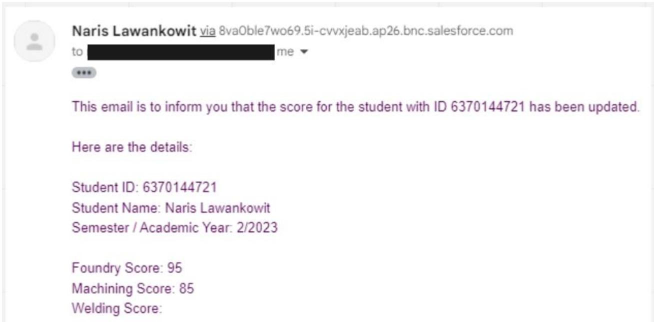

Fig. 22. Email sent from the Record-Triggered Flow.

7. Result and Discussion

7.1. Application Result

As we embark upon the exploration of the results from this study, the objective is to delineate the various functionalities embedded within the VR application, and the seamless flow they orchestrate to simulate Foundry and Heat Treatment operations in a virtual environment. The focal point will be the user's interaction with the application, underscoring the responsive nature of the application, and showcasing its efficacy as an indispensable tool for practical, hands-on learning and evaluation. The forthcoming analysis will elucidate the stepwise user journey within the application, starting with the commencement of the training mode, proceeding to the phase of evaluation in the assessment mode, and ultimately offering insights into the application's capacity to facilitate a deeply engaging and experiential learning process.

The Result and Discussion chapter delves into the step-by-step outcomes of the VR application for various stations within the Foundry and Heat Treatment processes. This comprehensive examination offers a detailed analysis of the results obtained from the Molding Station, Furnace Station, Workbench Station, and Heat Treatment Station. The upcoming content is captured using VR hardware (Fig. 23), offering an immersive perspective on the application.

Starting from the Main Menu (Fig. 24), the system needs to validate the credentials input by the user whenever the login button is clicked. This validation is done in the background by triggering the API call to Salesforce and validating the user's input for Student ID and Password with the Student_ID__c and Password__c fields in Salesforce's student record. If the credentials match, the user will then navigate to the Lab Selection Scene; otherwise, display an error popup to inform the user of incorrect credentials.

In the Lab Selection Scene (Fig. 25, Fig. 26), the user is allowed to switch between modes (Training and Exam) and select the scenes (Foundry Lab, Machining Lab, or Welding Lab). Upon switching mode to Exam, the system will validate and display the current score from the student record in Salesforce and disable the scene selection for those that are already complete. Once the mode and scene have been selected, the user is navigated to the corresponding scene.

The Foundry Lab Scene commences with the Molding Station (Fig. 27, Fig. 28, Fig. 29), this section offers a comprehensive insight into the user experience within the virtual environment, particularly in the context of mold creation. It underscores the VR application's remarkable precision in mirroring the intricacies of the molding process. Notably, the application's step-by-step guidance is emphasized, showcasing how users seamlessly navigate through complex actions with ease and confidence.

Subsequently, the spotlight shifts to the Furnace Station (Fig. 30, Fig. 31), where users embark on an immersive journey operating the virtual furnace. Here, the results vividly illustrate the experience of generating heat, managing molten metal, and manipulating furnace controls within the virtual realm. It paints a vivid picture of users' virtual work at this station, highlighting the application's ability to immerse them in realistic scenarios.

Transitioning to the Workbench Station (Fig. 32), the VR application's capacity to simulate intricate tasks conducted in this workspace is explored in detail. From component assembly to precision measurements and adjustments, this segment underscores how the application effectively guides users through critical tasks performed at the workbench. It exemplifies the application's role as a facilitator of skill development and comprehension in this domain.

Lastly, the Heat Treatment Station (Fig. 33) results bring to the forefront the VR application's prowess in replicating the complexities of the heat treatment process. Users engage in controlled heating, cooling, and tempering activities, shedding light on how the VR environment fosters skill development and deepens understanding of heat treatment intricacies.

Collectively, the step-by-step findings from each station unveil the VR application's remarkable capacity to provide an authentic and engaging learning experience. These results offer profound insights into the effectiveness of this innovative educational tool, further underscoring its potential to revolutionize learning in this domain.

Fig. 23. Application in Action: Running the Simulation via VR Hardware.

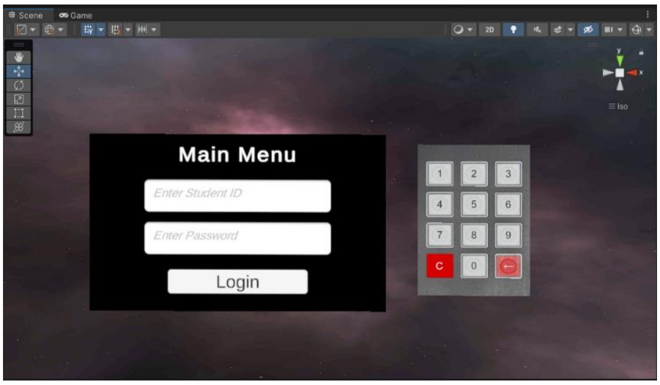

Fig. 24. Main Menu.

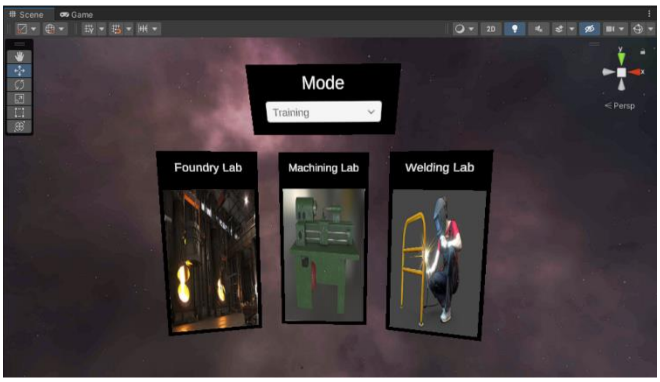

Fig. 25. Lab Selection Scene (Training Mode).

DOI:10.4186/ej.2024.28.6.1

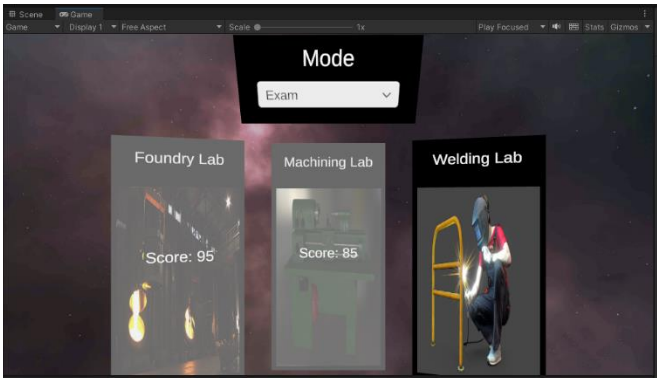

Fig. 26. Lab Selection Scene (Exam Mode).

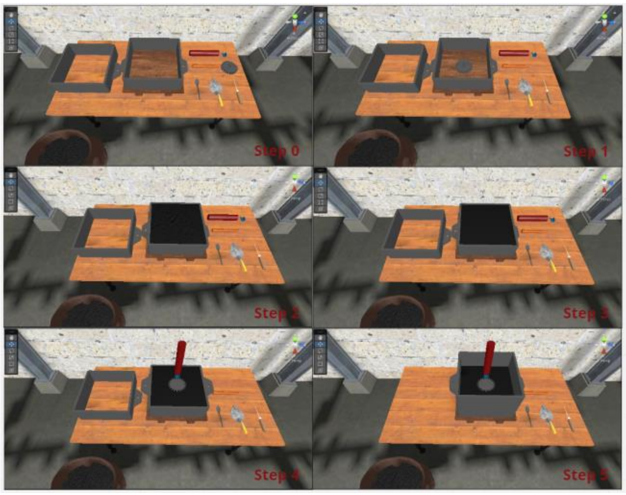

Fig. 27. Molding Station Step 0 – 5.

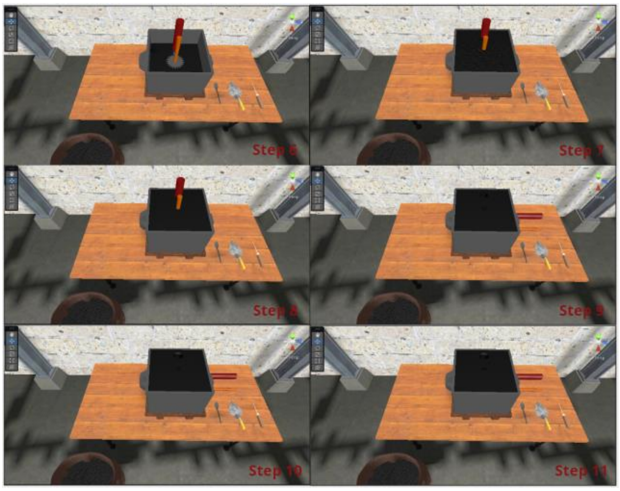

Fig. 28. Molding Station Step 6 – 11.

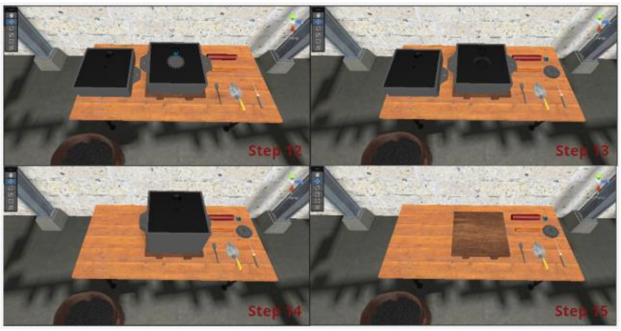

Fig. 29. Molding Station Step 12 - 15.

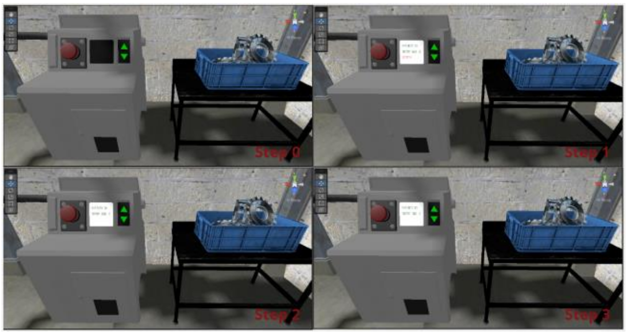

Fig. 30. Furnace Station Step 0 – 3.

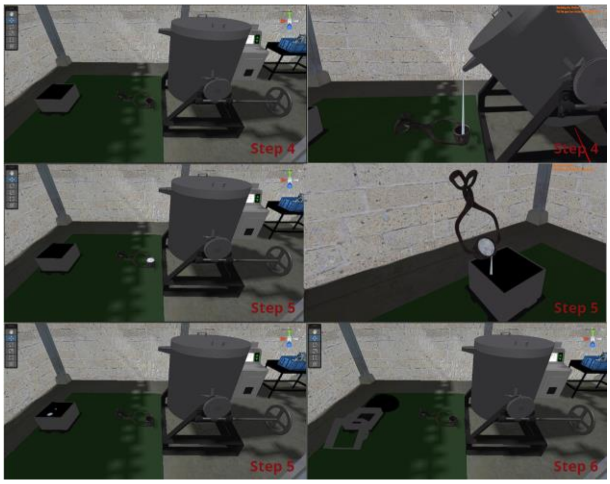

Fig. 31. Furnace Station Step 4 - 6.

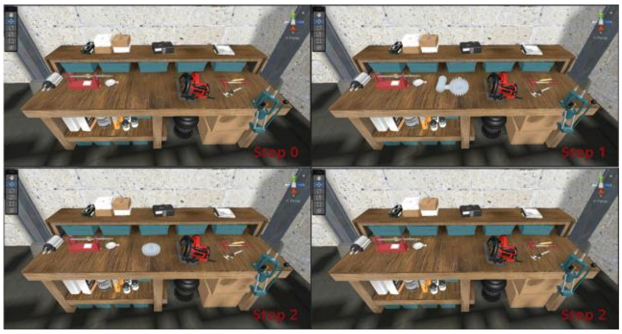

Fig. 32. Workbench Station Step 0 – 2.

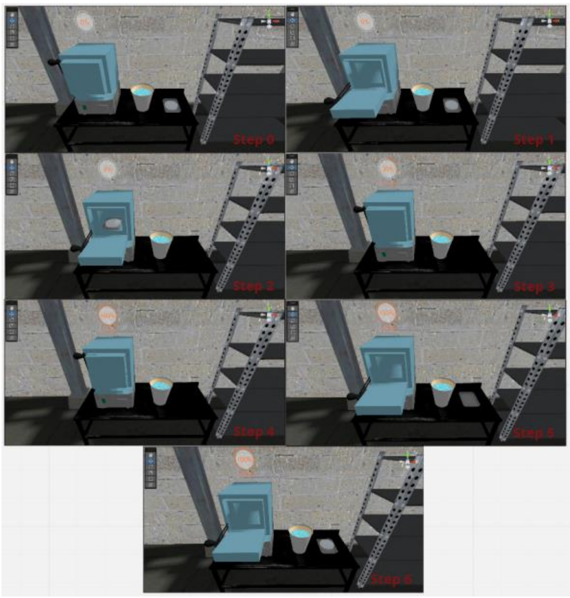

Fig. 33. Heat Treatment Station Step 0 – 6.

Once all the processes have been executed, the system concludes the session to be ended. While the session is ending, the system displays a message to inform the player that the lab has been completed while displaying the player's score. Then, the screen gradually fades away and navigates the player back to the Lab Selection scene. Simultaneously, for the exam mode, the system then records the player's score to their student record in Salesforce (Fig. 34) and sends out an email to inform the instructor of this student's course completion, consecutively.

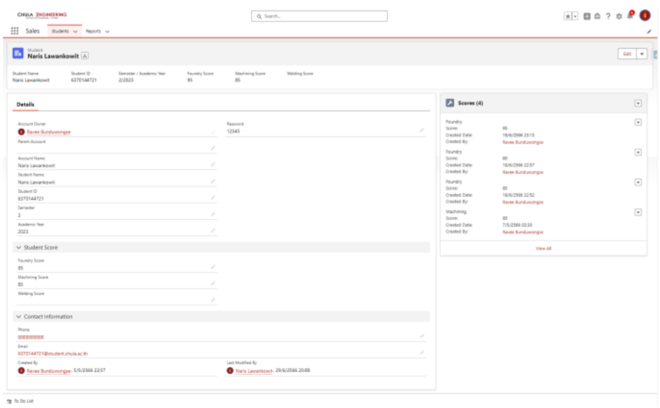

Fig. 34. Student record in Salesforce.

The outcomes derived from the VR application in the context of Foundry and Heat Treatment processes highlight its substantial merits as an educational resource. The application excels in delivering users a tangible, step-by-step walkthrough of the intricate processes encompassing molding, furnace operation, workbench tasks, and heat treatment. This immersive learning experience empowers users by imparting a nuanced comprehension of these industrial procedures, facilitating the development of essential skills and the acquisition of knowledge.

It's imperative to acknowledge that the VR application, although invaluable for demonstrating the flow of tasks, does not prioritize precise accuracy in task execution. Instead, its primary objective is to guide users through the essential steps of each process, ensuring a firm grasp of the fundamental concepts and procedures involved. In this regard, the application excels, providing a secure and hazard-free environment for users to practice and refine their skills.

Looking ahead, there exists ample scope for enhancing and configuring the application's scoring system. This adaptability enables the tailoring of assessment and evaluation mechanisms to align with the precision demands of real-world scenarios more closely. As technology continues to progress, the VR application can be adapted to offer more advanced simulations and refined scoring methodologies, promising an even more comprehensive and engaging learning experience for users. In conclusion, the results affirm the potential of this VR application as a transformative educational and training tool within the realm of Foundry processes, with a commitment to ongoing improvement in the future.

7.2. Comparative Analysis of Application Results and Real-World Processes

Within this dedicated section, our focus narrows to a critical examination, centering on the comparison between the application's results and both the foundry and heat treatment processes. It's worth noting that, unlike the heat treatment process, the foundry process introduces intricacies that enable us to discern significant distinctions. By employing side-by-side image comparisons that encapsulate identical stages in both the digital simulation and the actual foundry and heat treatment scenarios, our primary goal is to gauge the precision and effectiveness of the virtual model. This analysis serves as a pivotal bridge between the digital and tangible realms, yielding practical insights and validation, all the while shedding light on the captivating convergence of technology and reality, particularly in the context of the foundry and heat treatment processes.

Fig. 35. Virtual Reality Simulation vs. Actual Process - Set 1.

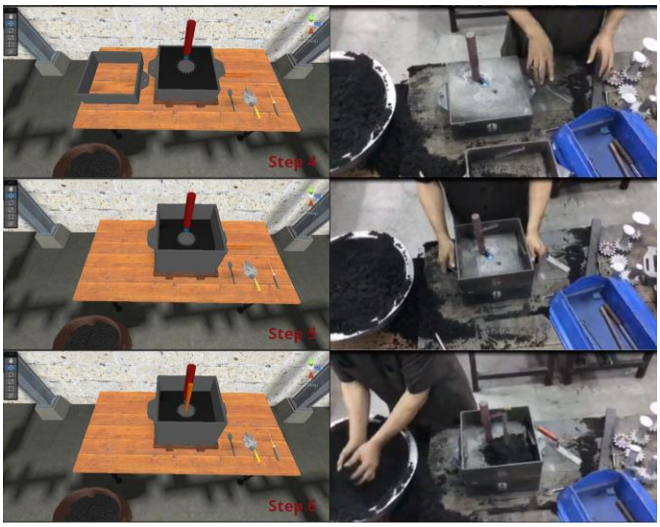

Fig. 36. Virtual Reality Simulation vs. Actual Process - Set 2.

DOI:10.4186/ej.2024.28.6.1

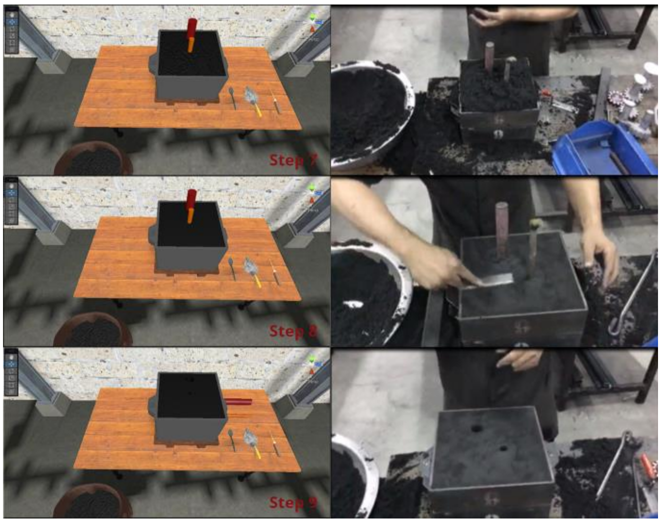
Fig. 37. Virtual Reality Simulation vs. Actual Process - Set 3.

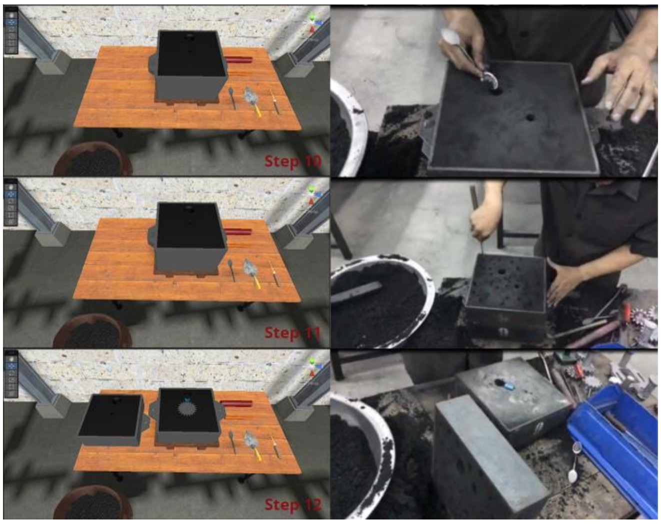
Fig. 38. Virtual Reality Simulation vs. Actual Process - Set 4.

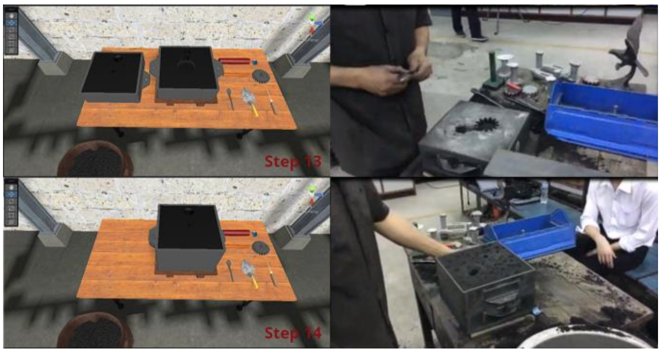
Fig. 39. Virtual Reality Simulation vs. Actual Process - Set 5.

While the workflow at the Furnace Station may have some variations, the application process offers a more user-friendly approach that effectively mirrors the real-world procedures.

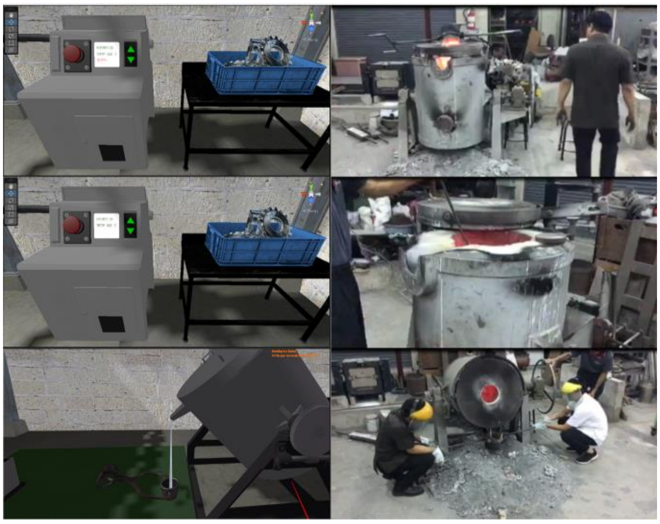
Fig. 40. Virtual Reality Simulation vs. Actual Process - Set 6.


Fig. 41. Virtual Reality Simulation vs. Actual Process - Set 7.


Fig. 42. Virtual Reality Simulation vs. Actual Process - Set 8.

Fig. 43. Virtual Reality Simulation vs. Actual Process - Set 9.

The analysis of the application's performance within the context of the foundry and heat treatment processes reveals a comprehensive representation. While it does leave some minor steps (Fig. 44, Fig. 45, Fig. 46, Fig. 47, Fig. 48), particularly in the pre-process or polishing phase, unaddressed, it is essential to note that the limitations of the VR environment hinder the application's ability to provide pinpoint operation accuracy. Nevertheless, the findings remain exceptionally valuable for practical applications, notably within the domains of training and learning. They offer a holistic and reproducible approach to grasping the intricacies of the foundry process and its workflow.

Fig. 44. Sand mulling step which mixes and blends the sand with binders and other additives, ensuring that the sand is well-distributed.

Fig. 45. Sand ramming step which improves mold strength and makes it dimensionally stable.

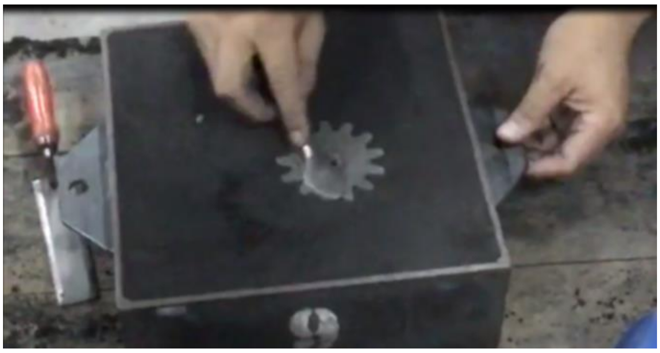

Fig. 46. Sand polishing step around the mold workpiece.

Fig. 47. Applying parting powder step to prevent the molding sand from sticking to the pattern or the mold box.

Fig. 48. Quenching step to rapidly cool down the workpiece.

Furthermore, the adaptable nature of the digital model opens doors for future enhancements, allowing for the inclusion of any missing steps as needed. In this regard, the application not only acts as a bridge between the virtual and tangible worlds but also functions as a robust tool for comprehending and mastering the complexities of the foundry and heat treatment processes. Its potential for continuous improvement and refinement underscores its significance as a dynamic resource in the field.

7.3. User Testing and Feedback

The instructors responsible for instructing students in the intricacies of the actual foundry and heat treatment processes offered their perspective on the application: "The application's alignment with the real-world process is truly commendable, with only minor steps left to address. It proves to be a valuable tool in helping our students better grasp the complexities of the foundry process. It seamlessly complements classroom theory, providing a cost-effective and safer alternative for practical demonstrations. Moreover, it enriches the learning experience by allowing students to gain a thorough, hands-on understanding of the workflow. What's particularly exciting is the system's automation, which effectively records each student's performance and scores. This application shows great promise and holds the potential for even greater usefulness in the future, especially if we consider expanding its feature set and achieving operational accuracy."

Upon closer inspection of the VR application's alignment with the actual industrial processes, with a few minor steps left unaddressed, the simulation is quite faithful. Despite the precision needed for the intricate operation, the application simplifies it into a user-friendly flow for easy learning. Step-by-step instructions enhance the learning experience, connecting theoretical knowledge with practical applications. The repetitive training feature lets users familiarize themselves with the operation, significantly improving skills compared to theoretical learning alone. However, there is room for improvement, particularly in providing comparative knowledge, such as material-specific melting points, and offering detailed information on how each step reflects the actual process. To enhance effectiveness, detailed knowledge and tips for each step could be added, and including operating accuracy may contribute to a more comprehensive scoring system. The acknowledgment of a 90% accuracy rating recognizes the application's excellence in simulating most steps. This evaluation is based on a thorough assessment of its performance in mirroring actual industrial processes. While the application excels in simulating most steps, addressing these opportunities could boost its accuracy beyond 95%, solidifying its status as a valuable educational tool, especially in academic curricula and industrial training.

In addition to the instructor's valuable insights, the section highlights ongoing efforts to enhance the application's educational value based on the feedback received. Notably, the instructor's observations underscore the application's positive reception for its alignment with the real-world foundry and heat treatment processes. Its ability to seamlessly complement classroom theory, providing a cost-effective and safer alternative for practical demonstrations, has established it as an asset in the educational toolbox. Furthermore, students have praised its role in enriching the learning experience by providing a thorough, hands-on understanding of the workflow.

Looking forward, there is a clear emphasis on improving various aspects of the application to make it even more effective. One key area of focus is the expansion of content coverage. While the current version aligns with fundamental concepts, there is a recognition of the importance of broadening its scope to encompass additional aspects and variations of the foundry process. This initiative aims to provide students with a more comprehensive understanding of the field, catering to both novice learners and those seeking a deeper insight into the intricacies of foundry work.

Operational accuracy is another critical aspect of ongoing improvement efforts. The commitment is to bring the digital experience into closer alignment with real-world procedures, enhancing the authenticity of the learning journey. This commitment stems from the desire to offer students a more lifelike and practical experience, ultimately advancing their skills and knowledge in the realm of foundry work.

These initiatives underscore a dedication to creating a highly effective and versatile learning tool that not only mirrors the complexities of the foundry and heat treatment processes but also evolves to meet the ever-growing demands of the educational landscape.

7.4. Performance Testing

The performance of the VR application has been commendable, offering users an immersive and informative experience in the realm of Foundry and Heat Treatment processes. However, as technology continually advances, it is imperative to strive for optimization and enhancement to ensure the application remains at the forefront of educational tools.

Recent upgrades to the system have led to significant improvements in performance. One notable enhancement is the implementation of advanced rendering techniques, which have resulted in smoother and more realistic graphics. This not only elevates the overall visual quality but also enhances user engagement by making the virtual environment even more lifelike.

Furthermore, optimizations in the application's codebase have led to improved responsiveness and reduced latency [28]. Users can now interact with virtual objects and machinery more seamlessly, mimicking real-world actions with greater accuracy. These upgrades have also allowed for the incorporation of more complex simulations, offering users a more detailed understanding of the intricate processes involved in Foundry and Heat Treatment.

Additionally, enhanced compatibility with a broader range of VR hardware ensures that a larger audience can benefit from this educational tool. Users can now access the application with a variety of VR headsets, making it more accessible to students and professionals alike.

7.5. Enhancement Discussion

In the future, there will be many interesting opportunities for the Virtual Reality (VR) application to be improved and expanded. The accuracy of task execution within the program may be one of the main areas of attention for further revisions. Although the present version does a good job of displaying process-based workflows, there are many complexities and variables that can affect how these procedures are used in the real world. Future iterations of the application might incorporate sophisticated simulation algorithms to replicate this complexity more accurately, enhancing the user's experience with realism and precision.

The functionality of the application could also be increased, which is another possible direction for improvement. Many other industrial processes could profit from similar VR-based training, even if the current emphasis is on Foundry and Heat Treatment procedures. New modules for these other processes could be added in later versions, expanding the functionality and value of the program.

Imagine the possibility for the VR application to incorporate Machine Learning algorithms, customizing the learning experience to each user's unique learning style and speed [29]. These advanced algorithms may dynamically modify the instructional content, creating a custom learning trajectory for everyone by methodically analyzing user behavior and performance. Increasing focus on areas where the user experiences difficulties or accelerating development in areas where the user excels may be part of this process. The result is expected to be a learning process that is more effective, efficient, and responsive to the demands and skills of the user. This illustrates how deeply machine learning can be incorporated into upcoming versions of the program.

The application's Salesforce connectivity is another essential area for improvement. The current version makes use of Salesforce's powerful data management and performance tracking features. Future iterations might, however, benefit from Salesforce's more sophisticated data analysis toolkits. These systems could give in-depth analyses of student performance and learning development, providing both students and teachers with useful feedback.

In summing up, the expansive horizons of technological progression offer boundless possibilities for the enrichment of this VR application. Each step forward promises to imbue the application with a greater depth of immersion, efficiency, and engagement in the learning process. The unwavering commitment to progressive refinement and evolution ensures that the application remains at the forefront of educational technology. This determination assures that the VR tool will persist as a leading-edge contribution to the ever-evolving panorama of virtual education.

8. Conclusion

This research has been focused on the development of a Virtual Reality (VR) application intended to educate users on Foundry and Heat Treatment operations. Prompted by the challenges posed by the COVID-19 pandemic, the necessity for effective virtual education mediums has never been more pronounced. The VR application presented herein provides a safe, accessible, and standardized method of instruction that can be deployed irrespective of geographical location or budgetary constraints.

The application is engineered to emulate the correct and safe procedures associated with these industrial processes, offering a risk-free learning environment. Despite not simulating viscosity and cooling during the pouring step of the Foundry process, it delivers users with a nuanced understanding of process-based workflows. The VR application has two unique modes: training and exam and is expertly constructed. Users are led through the procedure in the Training mode, with step-by-step instructions leading the way for an entertaining and educational experience. The Exam mode, on the other hand, tests the users' comprehension and application of the procedures, guaranteeing that the VR application acts not only as a tool for education but also as a thorough instrument for evaluating the users' understanding and execution of these activities.

The development process employed a comprehensive approach underpinned by technological acumen and systematic planning. Key resources included the Unity engine, 3D modeling software, and Salesforce for robust database capabilities. This multifaceted development process was crucial for creating immersive, realistic VR environments that both educate and evaluate users.

The main difficulties encountered during actual Foundry and Heat Treatment process activities are addressed in this VR application. It guarantees accessibility, removes physical hazards, offers economic effectiveness, and permits limitless repetition. Although it doesn't support high levels of task execution accuracy, it dramatically improves learning and training by solving key issues with conventional approaches.

In conclusion, the application's future iterations might concentrate on increasing task execution accuracy, perhaps by using cutting-edge simulation methods. Expanded functionality and machine learning methods for a more individualized user experience could be included as further improvements. Increasing the Salesforce integration might provide access to more powerful data analysis capabilities. With further technological development, this VR application has a lot of room for improvement, which bodes well for future learning experiences that are even more immersive, effective, and fun.

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