A Mixed Reality Approach for Merging Abstract and Concrete Knowledge

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ABSTRACT

Mixed reality's (MR) ability to merge real and virtual spaces is applied to merging different *knowledge types*, such as *abstract* and *concrete* knowledge. To evaluate whether the merging of knowledge types can benefit learning, MR was applied to an interesting problem in anesthesia machine education.

The Virtual Anesthesia Machine (VAM) is an interactive, abstract 2D transparent reality [14] simulation of the internal components and invisible gas flows of an anesthesia machine. It is widely used in anesthesia education. However when presented with an anesthesia machine, some students have difficulty transferring *abstract* VAM knowledge to the *concrete* real device.

This paper presents the Augmented Anesthesia Machine (AAM). The AAM applies a magic-lens approach to combine the VAM simulation and a real anesthesia machine. The AAM allows students to interact with the real anesthesia machine while visualizing how these interactions affect the internal components and invisible gas flows in the real world context.

To evaluate the AAM's learning benefits, a user study was conducted. Twenty participants were divided into either the VAM (abstract only) or AAM (concrete+abstract) conditions. The results of the study show that MR can help users bridge their abstract and concrete knowledge, thereby improving their knowledge transfer into real world domains.

CR Categories and Subject Descriptors: J.3 [Computer Applications]: Life and Medical Sciences – Health;
Additional Keywords: Mixed Reality, Modeling and Simulation, Anesthesiology, Psychology, User Studies

1 INTRODUCTION

One of the major benefits of Mixed Reality (MR) is the ability to merge real and virtual spaces. In a MR system, the user can interact with and visualize both real and virtual objects in the same context. For example, users could interact with a real world anesthesia machine as a tangible user interface and visualize an abstract simulation of the gas flows in the context of the real machine (figure 1). Through this merging of virtual (i.e. the abstract simulation) and real (i.e. the anesthesia machine) spaces, such a system might also enable the user to mentally merge the different *knowledge types* -- abstract knowledge learned from the simulation and concrete knowledge learned from the real machine. The purpose of this research is to discover if MR's merging of spaces can help the user to merge abstract and concrete knowledge.

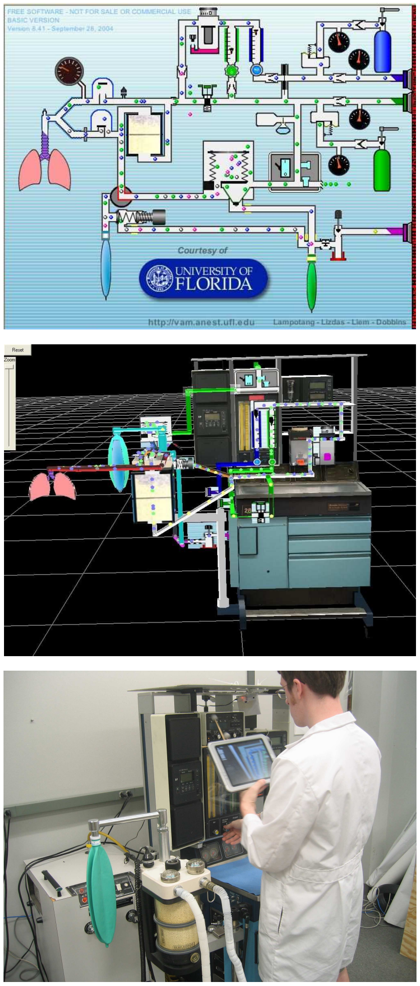

Figure 1. *Top*: the abstract VAM simulation. *Middle* - the AAM. *Bottom* – A user interacts with the AAM using a magic lens.

To investigate how MR impacts the merging of knowledge, this research uses MR to address a problem in anesthesiology education. Anesthesia educators have noted that some students have difficulty transferring the knowledge learned from an abstract simulation of an anesthesia machine – the Virtual Anesthesia Machine (VAM) (figure 1 top) -- to the real world anesthesia machine. This paper presents a Mixed Reality (MR) application, the Augmented Anesthesia Machine (AAM), as a potential solution to this problem.

The AAM uses MR to combine an anesthesia machine with the widely used VAM -- an interactive, web disseminated, abstract simulation of an anesthesia machine. By combining the VAM with an anesthesia machine, the AAM gives anesthesiology students the powerful abilities to (1) visualize an abstract simulation of the anesthesia machine's internal components and

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invisible gas flow, while (2) interacting with the real anesthesia machine as a tangible user interface.

The AAM was designed to improve transfer from the VAM to the real machine by employing the concept of multiple *representations*. For example, the VAM is an *abstract representation*. The real anesthesia machine is a *concrete representation*. The AAM facilitates new representations by *combining the abstract and concrete representations* (i.e. figure 1 middle). Research has shown that learning with multiple representations (i.e. abstract, concrete, *and* combined) can improve overall comprehension of complex concepts [17][18], such as anesthesia machine training concepts.

The research presented in this paper uses the AAM to determine if MR can utilize these multiple representations to improve the overall understanding of a concept. Specifically, this paper describes:

1. The application of the Augmented Anesthesia Machine (AAM).
2. Interaction and visualization techniques of the AAM that afford novel representations of the anesthesia machine.
3. A user study that was conducted to evaluate the AAM's learning benefits.

2 PREVIOUS WORK

This section outlines some of the MR research that has aided in the development of the AAM and has enabled its multiple representations. Specifically, this section will briefly overview: (1) tracking and registration techniques, (2) tangible interfaces, (3) Magic Lens displays, and (4) Integrative modeling.

2.1 Tracking and Registration Techniques

Registration research focuses on solving the problem of accurately aligning virtual objects with real objects so that they appear to exist in the same space [1]. One approach to registration is to affix fiducial markers to the real objects in the scene. There are many approaches to tracking fiducial markers such as the ARToolkit [11] approach or using stereo images to track retro-reflective IR markers [20].

2.2 Tangible User Interfaces

A tangible interface [8] is an interface that employs real objects "as both representations and controls for computational media."[19] For example, a classic interface for a computer simulation is a Graphical User Interface (GUI) in which the user clicks on buttons and sliders etc. to control the simulation. The main purpose of a GUI is for control. Like a GUI, a tangible user interface (TUI) is used for control of the simulation, but the TUI is also an integral part of that simulation – often a part of the phenomenon being simulated. Rather than just being a simulation control, a TUI also represents a virtual object that is part of the simulation. In this way, interacting with the real object (i.e. a real anesthesia machine) facilitates interaction with both the real world and the virtual world at the same time. For example, NASA engineers performed a virtual assembly using real tools in MR [15]. Through interacting with a real tool as a tangible interface, they were able to interact with the virtual objects and complete the assembly.

2.3 Magic Lens Display

Magic Lenses were originally created as 2D interfaces [2]. 2D magic lenses are movable, semi-transparent 'regions of interest' that show the user a different representation of the information underneath the lens. They were used for such operations as magnification, blur, and previewing various image effects. Each lens represented a specific effect. If the user wanted to combine effects, two lenses could be dragged over the same area, producing a combined effect in the overlapping areas of the lens. The overall purpose of the magic lens was to show underlying data in a different context or representation. This purpose remained when it was extended from 2D into 3D [21]. Instead of using squares and circles to affect the underlying data on a 2D plane, boxes and spheres were used to give an alternate visualization of volumetric data.

In Mixed and Augmented reality these lenses have again been extended to become tangible user interfaces and display devices as in [16]. With an augmented reality lens, the user can look through a lens and see the real world augmented with virtual information within the lens' 'region of interest' (i.e. defined by an ARToolkit pattern marker or an LCD screen of a tablet pc based lens). The lens acts as a filter or a window for the real world and is shown in perspective with the user's first-person perspective of the real world. Thus, the MR/AR lens is similar to the original 2D magic lens metaphor, but has been implemented as a 6DOF tangible user interface instead of a 2D graphical user interface.

2.4 Integrative Modeling

Integrative modeling - the concept of linking models together in the user interface - is discussed in [7]. Our work with the AAM is an extension of this concept, using mixed reality to realize the linkage with an effective form of human-machine interaction.

3 LEARNING WITH ABSTRACT AND CONCRETE REPRESENTATIONS

3.1 Overview

In the learning process [12][13], it can be beneficial to learn with both abstract and concrete representations of a concept. Concrete representations (i.e. the anesthesia machine) and abstract representations (i.e. the VAM) offer the student different types of knowledge.

Concrete Representations offer *Concrete Experience* – "tangible, felt qualities of the world, relying on our senses and immersing ourselves in concrete reality."[13] For example, the real anesthesia machine, a concrete representation, is effective for teaching procedural concepts and psychomotor skills, such as how to physically interact with a specific anesthesia machine. It also provides tactile feedback such as the feel of the fluted knob for setting oxygen flow.

Abstract Representations offer *Abstract Conceptualization* – "thinking about, analyzing, or systematically planning, rather than using sensation as a guide." [13] For example, the VAM, an abstract representation, teaches students about intangible concepts such as invisible gas flow, which can be applied to many anesthesia machine models. Currently, students train with both the VAM and the real anesthesia machine representations to gain a broader understanding of anesthesia machines.

The remainder of this section describes the current anesthesia machine learning process and an issue that some anesthesiology educators have experienced. Then, the next section describes how MR can offer multiple representations to ameliorate some of the transfer problems with the current learning processes.

3.2 The VAM: An Abstract Representation

Seventy-five percent of anesthesia machine related operating room incidents resulting in patient death or permanent brain damage are due to user error [4]. The other twenty-five percent is due to machine failure. User errors occur because the anesthesia provider does not properly understand the machine, how it functions and how it should be used. In the event of an intra-operative anesthesia machine failure, without adequate knowledge about the anesthesia machine, the anesthesia provider may not be able to detect, identify and address the problem before patient injury occurs. For enhanced patient safety, the anesthesia provider must have a good understanding of the internal gas flows, the functions, and the relationships of the internal components within the anesthesia machine.

To address this problem, anesthesia educators created the now widely used Virtual Anesthesia Machine (VAM). The VAM is an interactive, online, abstract 2D transparent reality [14] simulation of the internal components and invisible gas flows of an anesthesia machine. This transparent reality approach emphasizes internal processes and structure at the expense of visual fidelity and resulted in enhanced comprehension compared to an opaque, photorealistic instantiation of an identical model of the anesthesia machine [5,6]. Since 1999 the VAM user base has grown to 30,000 registered users and the VAM website (http://vam.anest.ufl.edu) has 10 million hits per year.

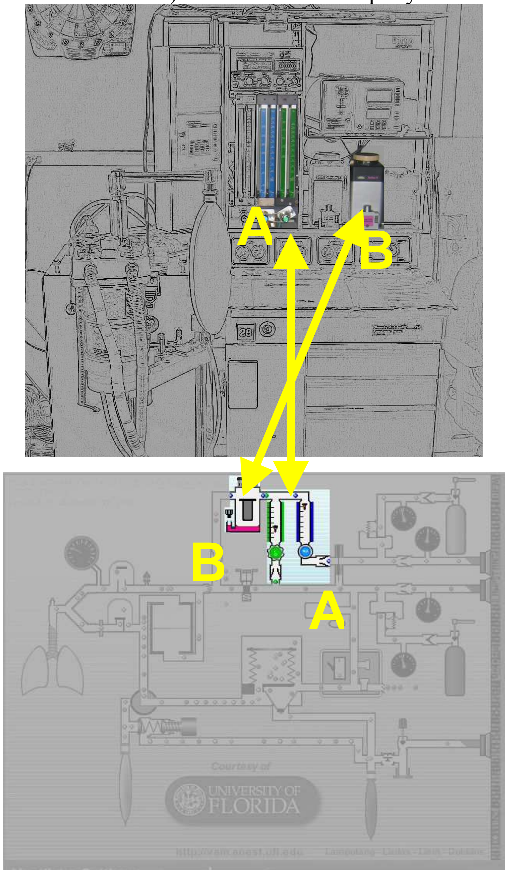

Figure 2. Top: a real anesthesia machine with the flow meters (A) and the vaporizer (B) highlighted. Bottom: the flow meters and vaporizer are spatially reversed in the abstract representation of the Virtual Anesthesia Machine (VAM).

The VAM's abstract representation offers several major learning benefits over a real anesthesia machine:

- Users can visualize internal components usually hidden from view and track invisible gas flows in the simplified anesthesia machine plumbing.
- The anesthesia machine components have been spatially reorganized in the VAM to make the gas flow animation more convenient to visualize, easier to understand, and applicable to different anesthesia machine designs.
- The VAM is easily disseminated online.

By visualizing and interacting with the VAM's abstract representation, the user can learn how the gas particles flow between the components of the anesthesia machine. This gas flow cannot be directly observed in a real anesthesia machine. For example, consider figure 2. In the real anesthesia machine, there is a hidden pneumatic connection between the flow meters (A) and the vaporizer (B). By observing the real machine, a student could not learn that gas flows from (A) to (B). However, In the VAM, this pneumatic connection is: (1) visualized, and (2) simplified due to the spatial reorganization of (A) and (B). The color-coded gas particles flow through the visualized piping to demonstrate the flow between (A) and (B). The VAM visualization enables anesthesiology students to better understand the gas flow. This understanding is necessary for anesthesia providers to operate the machine properly and safely and, in the rare event of machine failure, to quickly assess the situation and execute the best course of action for the patient.

3.3 The Anesthesia Machine: a Concrete Representation

The VAM simulation is used in parallel to practice with a real anesthesia machine in the operating room. The anesthesia machine gives students the concrete experience of physically interacting with a real anesthesia machine. They learn to interact with the machine by pressing the buttons, turning the knobs and reading the gas flow meters for example. This gives students the procedural knowledge and psychomotor skills that anesthesia providers need to safely deliver general anesthesia with a real anesthesia machine.

3.4 Problems Mapping Between Concrete and Abstract Representations

The VAM simplifies and reorganizes physical relationships such as the relative distance, position and orientation of the anesthesia machine's components. Not all learners have the same learning style. While VAM helps with conceptual understanding for the majority of learners, this spatial reorganization and abstract representation may make it difficult for a subset of students to orient themselves to the real machine. As an example, in a recently completed study comparing VAM to an equivalent black box photorealistic simulation, 8 out of 39 (~20%) preferred the photorealistic simulation to VAM [6].

For example, the gas flow meter controls in the VAM (figure 2 A) have been spatially reversed. The reason for this is that the VAM is an abstract representation – it simplifies the gas flow path to make the component relationships easier to visualize and understand. However, a novice student could oversimplify the concept of the meters in VAM. The student could memorize to turn the left knob CCW to increase the O_2. When the student interacts with a real anesthesia machine, he or she might turn the left knob CCW and accidentally increase the N_2O instead. This could result in (1) negative training transfer, and (2) setting an incorrect gas mixture.

4 USING MR TO MERGE CONCRETE AND ABSTRACT KNOWLEDGE

Training that uses only abstract and concrete representations (as in current anesthesia machine training) may be made more effective when there are additional representations that *span the abstract and the concrete* [10]. MR technology can enable these additional representations. For example, consider one of the representations implemented by the AAM in figure 1 middle. The VAM components have been spatially reorganized and registered to the corresponding components of a real machine. Students can visualize the gas flow in the context of the real machine with an MR display device (i.e. a Magic Lens). Moreover, synchronizing the gas flow simulation to the meters and gauges of the real machine allows students to interact with the simulation through their natural interaction with the real machine. By allowing users to interact with and visualize the VAM in the context of the real machine, the AAM helps users to better understand the relationships between the abstract VAM simulation and the anesthesia machine.

Learning with multiple representations (i.e. the VAM, the AAM, *and* the anesthesia machine) of a concept may improve overall comprehension of the concept. Multiple representations reduce *reductive biases* -- the oversimplification of a concept -- which is a common mistake among novice users [18], like new anesthesiology students. The AAM combines the concrete representation of the anesthesia machine with the abstract representation of the VAM. This enables multiple representations of the anesthesia machine. These representations may improve training transfer between the abstract representation and the concrete representation (figure 3).

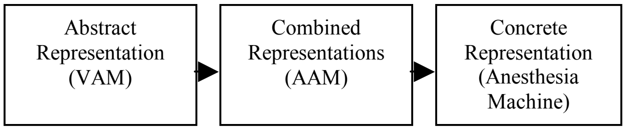

Figure 3. The anesthesia machine learning process augmented with the AAM. The AAM bridges the learning gap between the abstract and concrete representations of the VAM and the anesthesia machine.

4.1 AAM Representations

The AAM augments the current learning process with two new representations: (1) AAM-Abstract and (2) AAM-Concrete. These representations are intended to offer a smoother transition from the VAM's abstract representation to the anesthesia machine's concrete representation. This section describes the AAM's two new representations in detail.

4.1.1 The AAM-Abstract Representation

In the augmented learning process, AAM-Abstract is the first representation that begins to integrate the VAM with the real machine. In this representation, users visualize the VAM but interact naturally with the real machine instead of using a mouse and sitting at a desktop computer. Users can walk freely around the real machine, turn the real knobs, and press the real buttons while visualizing the impact of these interactions on the 2D VAM simulation, displayed on an untracked tablet pc (figure 4). This representation allows the user to better understand how to interact with the real machine and how the real machine interaction influences the 2D VAM simulation. This representation relates the concrete and tactile experience of real machine interaction to the abstract concepts learned from the 2D VAM.

AAM-Abstract's visualization is mostly 2D and almost identical to the VAM. The major difference is the 3D modeled anesthesia machine components that are registered to the VAM components. These models help to orient students by demonstrating the relationship between the VAM components and the anesthesia machine components.

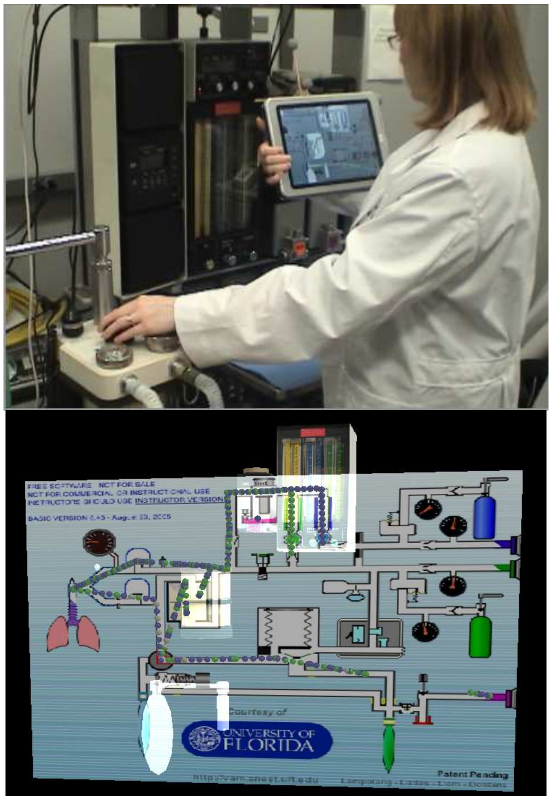

Figure 4. Top: A user interacts with the real machine while viewing the resulting AAM-Abstract visualization on an untracked tablet pc. Bottom: the AAM-Abstract visualization shown from the user's perspective.

4.1.2 The AAM-Concrete Representation

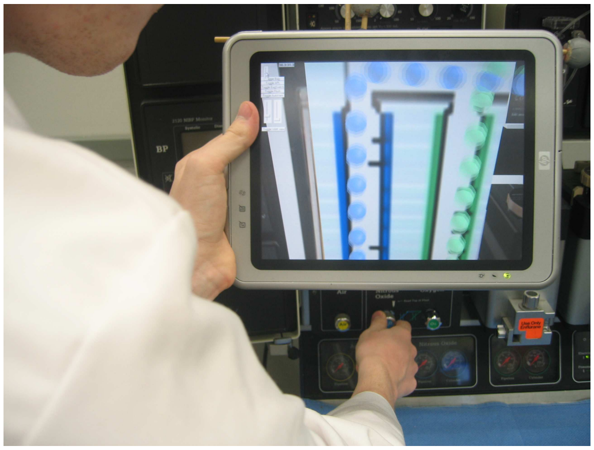

Figure 5. A user turns a gas knob on the real machine and visualizes how this interaction affects the overlaid VAM simulation.

The AAM-Concrete representation allows the user to take full advantage of the benefits of the MR technology. The user interacts with the real machine and visualizes the spatially reorganized VAM components registered to the corresponding components of the real machine from a first person perspective. For the visualization, the user looks through a hand-held magic lens -- a tracked 6DOF tablet pc display. The lens acts as a see-through window into the world of the 3D simulation (figure 5).

This visualization allows the user to see how the VAM simulation flows in the context of the real machine.

Conceptually, the VAM components are ‘cut out’ of the VAM and ‘pasted’ over the corresponding parts of the real machine (figure 1 middle). The collocation of the VAM components and the real anesthesia machine components demonstrates the relationships between the VAM and the anesthesia machine. By visualizing the collocated components, students may gain a better orientation to the layout, the function and inter-relationships of the real anesthesia machine components.

5 AAM SYSTEM DESCRIPTION

The AAM consists of an anesthesia machine augmented with MR technology (tracking systems, magic lens). This section will describe the implementation details of the AAM system. Specifically, this section will explain the details of the magic lens display and tracking technology that the AAM uses to (1) register the VAM with the real machine and (2) interact with the machine as a tangible user interface

5.1 Magic Lens Display

To visualize the AAM-Concrete, users look through a *magic lens,* a 6DOF tracked HP tc1100 Tablet PC (figure 6). Students can view the real machine from a first person perspective with a registered VAM simulation shown in context with the real machine. The anesthesia machine displayed on the lens appears in the same position and orientation as the real anesthesia machine, as if the lens was a transparent window and the user was looking through it.

Figure 6. A view of the anesthesia machine vaporizer (top) and the magic lens view of the vaporizer simulation (bottom) shown from the same viewpoint.

However, the lens in the AAM is not actually see-through. There are no cameras mounted on the lens that would allow the user to see through the lens. Instead of visualizing the real machine directly through the lens, the user sees a high-resolution scale 3D model of the machine that is registered to the real anesthesia machine. Using the lens’s position and orientation information along with the pre-computed position of the real machine, the lens can display the 3D model of the machine from a perspective that is consistent with the real machine. Thus, to the user, the lens appears to be see-through. We decided against using true video see through for two reasons: (1) Ergonomics: It would increase the hardware and weight of the lens (2) Registration between the simulation and the machine would be less stable with video see through. However, in the future we will explore other display options such as a true video see through magic lens or a Head Mounted Display.

5.2 Tracking Systems

There are two separate tracking systems used in the AAM. One system tracks the position and orientation of the magic lens, while the other system tracks the meters and gauges of the real anesthesia machine -- a Modulus II (Ohmeda, Madison, WI.) These enable the anesthesia machine to be used as a Tangible User Interface (TUI) for the visualized VAM simulation.

5.2.1 Tracking the Magic Lens

To track the position and orientation of the magic lens, the AAM tracking system uses an outside-looking-in optical tracking technique (figure 7). The tracking method is widely used by the VR/MR community [20]. The lens tracking system consists of two stationary webcams (Unibrain Fire-I, 640x480, 30 FPS) with software that calculates the position of retro-reflective markers that are attached to the objects being tracked (i.e. the magic lens). The specifications of the system are as follows: Tracking Volume: 5x5x5 m; Accuracy: 1cm; Jitter: 5mm; Latency: 70ms.

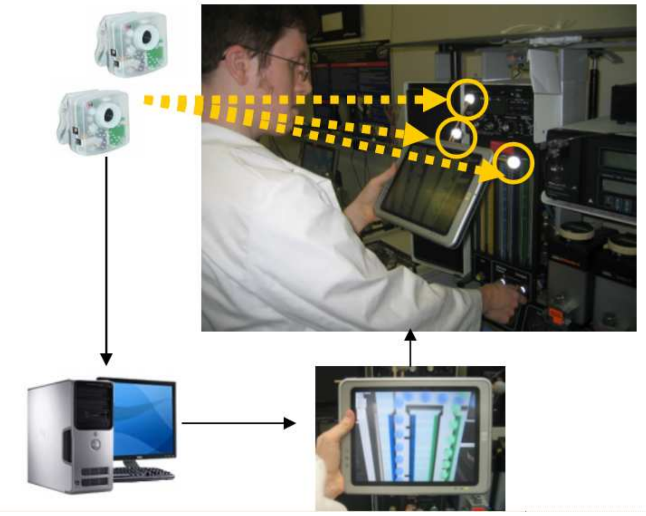

Figure 7. The magic lens tracking system.

To maintain the window metaphor, the 3D graphics displayed on the lens must be rendered consistently with the user’s first-person perspective of the real world. In order to display this perspective on the lens, the tracking system tracks the 3D position and orientation of the magic lens display and approximates the user’s head position.

5.2.2 Tracking the Anesthesia Machine’s Meters and Gauges

To enable the Anesthesia Machine as a TUI, the abstract simulation is synchronized to the real machine. To perform this synchronization, the AAM tracking system tracks the input and output (i.e. gas meters, pressure gauges, knobs, buttons) of the real machine and uses them to drive the simulation. An OpenCV [3] driven 2D optical tracking system with 3 webcams is employed to detect the states of the machine. State changes of the input devices are easily detectable as changes in 2D position or visible marker area, as long as the cameras are close enough to the tracking targets to detect the change in position. For example, to track the machine’s knobs and other input devices, retro-reflective markers are attached and webcams are used to detect the visible area of the markers. The machine's pressure gauge and bag are more difficult to track since retro-reflective tape cannot be attached to them. Thus, the gauge and bag tracking system uses color based tracking (i.e. the 2D position of bright red gauge pin).

Many newer anesthesia machines have an RS-232 digital output of their internal states. With these machines, optical tracking of the machine components may not be necessary. This minimizes the hardware and makes the system more robust. In the future, we will likely use one of these newer machines and eliminate optical tracking of the anesthesia machine components. This optical system was used for prototyping purposes. Surprisingly, we found that the optical system was quite effective and robust, as will be demonstrated by the user study section that follows.

6 USER STUDY

6.1 Overview

A study was conducted to evaluate if MR's merging of real and virtual spaces can effectively enable the merging of the user's abstract and concrete knowledge. The user study was conducted using the AAM as the testing environment. We conducted a between subjects user study with 20 participants. Ten participants completed a learning session with the AAM (Group AAM) and 10 participants completed a learning session with the VAM (Group VAM). In the study, we wanted to investigate if the combined representation of AAM-Concrete would significantly improve anesthesia machine understanding and transfer to the real machine. AAM-Abstract was not used for this study due to limitations on the number of participants.

Hypotheses:

H1: The abstract representation VAM is more effective at teaching abstract concepts

H2: The AAM is more effective at teaching concrete concepts

H3: The AAM improves transfer to the real machine by enabling the merging of abstract and concrete knowledge.

6.2 Population

There were 20 participants in this study (4 males, 16 females). All the participants were college students in an Introduction to Psychology class. Students in this class are required to participate in a number of studies for credit in the course. Thus, all the participants received credit for their participation in the study. The study protocol was approved prior to data collection by the University of Florida IRB (#2007-U-688).

6.3 Study Environment

The study was conducted in a quiet, air-conditioned room. In each study session, there was one participant and one investigator in the room for the duration of the session.

6.4 Study Procedure

For each participant, the study was conducted over a period of two consecutive days to minimize the risk of assessing superficial and short-term learning. The first day included several spatial cognitive tests and an anesthesia machine training module. The second day included 2 tests on anesthesia machines: a written test and a hands-on test with the real machine. The second day also included several questionnaires about subjective opinions of the learning module and personal information (i.e. computer usage and experience, GPA etc).

Prior to arriving to the study, participants were unaware of all the details of the study (i.e. they did not know it was about anesthesia machine training). When they arrived, they were given an informed consent form that gave them an overview of the study procedure. The procedure is as follows:

***Day 1 (~90 minute session)*:**

1. Introduction to the VAM:
Once participants finished the informed consent process, they were asked to put on a white lab coat so that they would "feel more like an anesthesiologist." The lab coat was also to reduce potential problems with the clothes of the participants interfering with the color trackers. Participants were handed a manual which provided them an introduction to the VAM. The manual was used in conjunction with an online interactive tutorial (http://vam.anest.ufl.edu/simulationhelp.html), which highlighted and explained each of the major VAM components and subsystems.

2. Relating the VAM to the Anesthesia Machine: The purpose of this was to familiarize the participants with how each VAM component represents a part of the real machine. Group AAM used the magic lens to visualize each VAM icon that represented a real component underneath, Group VAM moved their cursor over each VAM component with their mouse and were shown a *picture* of the corresponding real component. Since the VAM is an online educational resource, we only allowed students to view the component pictures (rather than the real component in person). This made the VAM interaction closer to how students typically interact with the VAM (i.e. online).

3. Complete 5 exercises: Each participant completed the same 5 exercises by following the manual and either interacting with the VAM or AAM-Concrete. Each of the exercises focused on a specific anesthesia machine concept (i.e. a particular component or subsystem).

4. Spatial Cognition Tests: Participants were given three tests to assess their spatial cognitive ability: (1) The Arrow Span Test, (2) The Perspective Taking Test and (3) Navigation of a Virtual Environment. Each of these is outlined in [22].

Day 2 (~60 minute session):

1. Self Evaluation: Participants were asked to rate their proficiency in overall anesthesia machine understanding that was gained from the previous day.

2. Written Anesthesia Machine Test: The purpose of this test was to assess abstract knowledge gained from the previous day of training. The test consisted of short answer and multiple choice questions from the Anesthesia Patient Safety Foundation anesthesia machine workbook. Participants did not use the AAM or the VAM to answer the questions. They could only use their retained machine knowledge and experience.

3. Machine Component Review: VAM participants were shown each 2D component in the VAM and then the investigator pointed at the real machine component. For Group AAM, the investigator pointed at each real component and the participant held the lens over the component. No additional information was given to either group. The purpose of this review was to prepare the participants for the hands-on tests that followed.

4. Hands-on Anesthesia Machine Fault Test: A 'hands-on' test was used to test participant's concrete knowledge gained from the previous day of training. For this test, participants used only the anesthesia machine without any type of computer simulation. The investigator first caused a problem with the machine (i.e. disabled a component). Then the participant had to find the problem and describe what was happening with the gas flow.

5. Demo of VAM/AAM: Group AAM participants were briefly reintroduced to the VAM. Group VAM were introduced to the AAM. This interactive demo lasted approximately 2-3 minutes.

6. Personal/Subjective Questionnaires: Participants were asked several personal questions (i.e. computer experience, GPA, etc.). They were also asked which simulation (VAM or AAM) they would prefer for future study and why.

6.5 Metrics

Time to Complete the 5 Exercises - Participants were timed as they worked through the 5 main exercises.

Written Anesthesia Machine Test – This test was multiple choice and gave an overall score of a participant's abstract knowledge.

Hands-on Anesthesia Machine Fault Test – Participant performance on this test was assessed on one metric: if the participant was able to identify the problem causing the machine fault. Participants were given as much time as they needed and stopped when they either identified the problem or quit. This test assessed the participants' concrete knowledge of the machine

6.6 Results and Discussion

Table 1. Written Test Results (out of 116 possible points)

Group	Average Points	Stdev
AAM	39.89	15.04
VAM	51.80	23.71

Table 2. Fault Test Results

Group	# Participants Successful
AAM	6 out of 10
VAM	1 out of 10

Table 3. Significance differences in tests

Written Test	p = 0.2144
Machine Fault Test	p = 0.0176

6.6.1 Written Test Discussion

There were no significant differences (p = 0.2144) between groups on the written tests (table 3). Note that these tests assessed mostly abstract knowledge. For example, one question asked, "Is the inhalation valve bidirectional or unidirectional and why?" To correctly answer this question, one would need a deep understanding of the flow of invisible gasses in the machine. The VAM has been shown to effectively teach abstract concepts [6]. Since there were no significant differences, we hypothesize that both the AAM and the VAM were effective in teaching these concepts.

However, on average, Group VAM scored higher on the written tests (table 1). Because the VAM uses an abstract, simplified spatial organization, abstract concepts such as gas flow are easy for students to visualize in the VAM context. *Because the VAM is an abstract representation, it is likely more effective in teaching abstract concepts.*

6.6.2 Fault Test Discussion

There was a significant difference between the groups in the performance of the Fault Test (p=0.0176) (table 2).The fault test assessed participants' concrete knowledge of the machine by forcing them to interact with the machine without the use of a simulation. In this test, the participant was first sent outside of the room. The investigator then removed a small, yet vital piece of the inhalation valve (called the leaflet). This simulated a leak in the valve. In a real scenario, this leak would cause the patient to rebreathe carbon dioxide. When participants returned to the room, at first glance the system appeared to be operating normally (i.e. there were no alarms sounding). Participants had to detect and identify that a small piece was missing from the inhalation valve and that it could be potentially harmful to a patient. Significantly more participants in Group AAM identified the fault on this test. This demonstrates that training with AAM offered students improved concrete knowledge of the machine. *Thus, we accept the hypothesis the AAM is more effective than the VAM in teaching concrete concepts*.

Although the VAM may offer improved abstract knowledge, participants found it difficult to transfer this knowledge to the concrete anesthesia machine. This is precisely the concern that educators have had with the VAM and other abstract representations. For example, many VAM participants understood the abstract concept of the inhalation valve and they correctly answered the written questions regarding the gas flow in the valve (i.e. the example question from section 6.6.1). However, during the fault test, they could not perform the mental mapping between the abstract representation of the VAM inhalation valve and the concrete representation of the real anesthesia machine inhalation valve. Thus, it was difficult for VAM participants to apply their abstract knowledge to a concrete problem, such as the problem presented in the fault test.

One of the major benefits of the AAM is that it affords participants a better transfer of abstract and concrete knowledge when interacting with the real machine. To properly complete the fault test, participants had to notice that a piece of the inhalation valve was missing (i.e. concrete knowledge of this specific machine) and realize that this missing piece could cause problems with gas flow (i.e. abstract knowledge of the machine). To solve this problem, participants had to merge their concrete and abstract knowledge of the machine. In this merging task, AAM participants performed significantly better than VAM participants. *This leads us to accept our hypothesis that the AAM effectively enables the merging of abstract and concrete knowledge.* (Supporting results are shown in tables 1, 2, and 3)

6.6.3 Training Time Discussion

Table 4. Time to complete the 5 training exercises

Group	Average	Stdev
AAM	37.9	12.48
VAM	22.9	4.36

A potential confound is that group AAM took significantly longer (p = 0.002) than group VAM to complete the 5 training exercises on the first day (table 4). Group AAM's increased training time could have affected fault tests. However, there was no significant correlation (correlation = 0.0965) between AAM training time and success on the fault test. *Thus, training time had a minimal effect on the fault test results.*

However, the VAM's decreased training time does highlight that the VAM is more efficient for teaching abstract concepts. In the AAM more time is used interacting with the real machine, which slowed the participants' training more than the VAM's mouse interface. Although their written test scores were not significantly different, group VAM took significantly less time to complete the exercises than group AAM. Thus, *we accept the hypothesis that the VAM is more effective at teaching abstract concepts.* The VAM is more adept at introducing abstract concepts, whereas the AAM is better at introducing the application of these abstract concepts in the "real world."

7 CONCLUSIONS AND FUTURE WORK

The AAM uses MR technology to combine a real anesthesia machine with its corresponding 2D abstract simulation -- the VAM. This combination was created to resolve a critical learning transfer problem from the VAM to the real machine. This paper outlined the AAM's two new representations of the anesthesia machine and presented a user study that evaluated the methods of improving transfer from abstract to concrete representations. As demonstrated by the study, the AAM's new machine representations enable an improved transfer from the abstract VAM to the concrete anesthesia machine. We propose that the AAM be used as an intermediary learning module that bridges VAM training and real anesthesia machine training.

Psychology research has shown that learning with multiple representations that *span* from abstract to concrete are beneficial in learning difficult concepts [9][10][12][18]. The results of our user study with the AAM support this research and demonstrate that the AAM is effective in bridging the learning gap between an abstract representation (the VAM) and a concrete representation (the real anesthesia machine). This suggests that MR's merging of real and virtual spaces can improve the user's merging of abstract and concrete knowledge. This demonstrates that *MR is an effective educational tool that can bridge abstract and concrete knowledge in the learning process.*

In the future, we will continue to explore how MR impacts learning and the merging of knowledge. The study presented in this paper is the first part of a larger study in which we will evaluate the individual aspects of MR (such as overlaid virtual objects and tangible user interfaces) and how each affects learning. Specifically, we will run this study with more conditions. Some participants will train without simulation -- with only a real anesthesia machine. Other participants will train with a 3D simulation only – the AAM simulation with a mouse-keyboard interface and without tracking. By comparing these conditions with our current two conditions, we will be able to determine how the combined spaces of MR affect learning and knowledge merging. Hopefully, we can also identify what types of learners most benefit from MR's merging approach. (We expect this is somehow correlated to spatial ability). In addition, we will use MR to merge other abstract simulations with their corresponding devices (i.e. other medical devices like a dialysis machine) and compare the learning benefits of these systems to our current system, the AAM.

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