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Technical Section

Scaffolded learning with mixed reality

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ABSTRACT

Scaffolding is a widely used educational practice in which directed instruction gradually decreases as student competence increases—resulting in increased independent learning. This research introduces and evaluates an MR-based system for technology-mediated scaffolding in anesthesia education. Through merging real and virtual objects, the system addresses a vital problem in merging abstract and concrete knowledge. To evaluate the system, a user study was conducted ($n = 130$). Results suggest that MR's merging of real and virtual spaces can offer (1) a unique level of educational scaffolding, and (2) an improved learning-transfer from abstract to concrete domains.

To classify the presented system, the virtuality continuum is extended to include scaffolding. The presented scaffolding-space continuum classifies technology-mediated scaffolding tools along three orthogonal continuums: (1) virtuality, (2) information (e.g. abstract, concrete), and (3) interaction. Using these 3 orthogonal continuums, effective engineering approaches for technology-mediated educational scaffolding are described.

1. Introduction

This research focuses on how mixed reality (MR) can enable novel scaffolded learning approaches. Scaffolding is an educational process whereby educators gradually decrease directed instruction (e.g. the level of detail of the instruction) as students become more competent at a task. This approach has been shown to promote independent learning, which is an important skill when students encounter new challenges. Although educators have implemented scaffolding for many years [1], recently there has been a need for new technologies that enable scaffolding. This research describes how MR can enable novel scaffolding tools (e.g. gradually decreasing the proportion of virtual objects in an MR scene as the user gains competence) that offer students vital learning benefits, such as improved training-transfer to real-world scenarios.

To investigate how MR impacts scaffolding, this research uses MR to address an educational challenge in anesthesia education. In the anesthesia education process, many students first learn about anesthesia machines by interacting with an abstract simulation of an anesthesia machine—the virtual anesthesia machine (VAM) (Fig. 1). This simulation has been shown to be very effective in teaching students about abstract concepts such as invisible gas flow [2]. However, anesthesia educators have noted that some students may have difficulty transferring the knowledge from VAM to the real-world anesthesia machine. It was suggested that there was a need for additional scaffolding to facilitate a smoother transition between the VAM and the real machine.

As a potential solution to this problem, this paper presents an MR-based scaffolding tool—the augmented anesthesia machine (AAM) (Figs. 2 and 3). The AAM combines 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 critical ability to visualize an abstract simulation of the anesthesia machine's internal dynamic model components and invisible gas flow, while interacting with the real anesthesia machine as a tangible user interface.

To describe how MR in general can enable scaffolding, we propose to extend the virtuality continuum [3] to scaffolding-space continuum (SSC). The SSC is made up of three orthogonal continuums: (1) the virtuality continuum, which varies from real to virtual, (2) the information continuum, which varies from abstract to concrete (e.g. the VAM is abstract and the real machine is concrete), and (3) the interaction continuum which also varies from abstract to concrete (e.g. the VAM employs 2D, abstract interaction, the real machine employs physical, concrete interaction). Within the space of the SSC, an effective scaffolding approach would utilize a set of systems (e.g. VAM, AAM, real anesthesia machine) along a curve or a line (e.g. interpolating between abstract and concrete as the user gains competence).

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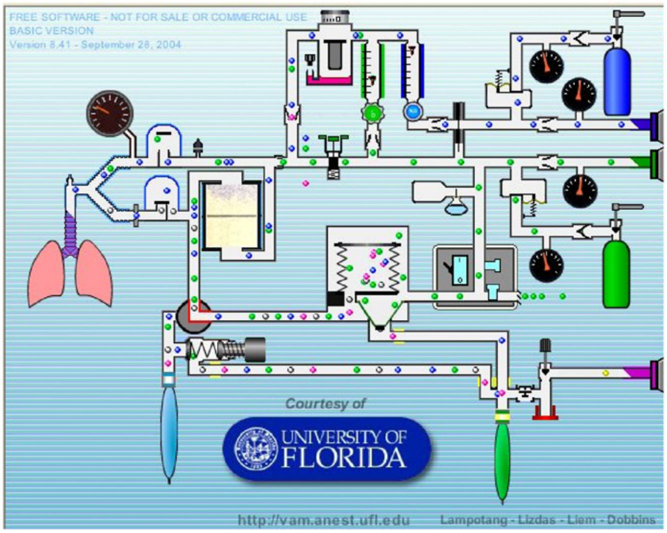

Fig. 1. The abstract VAM simulation.

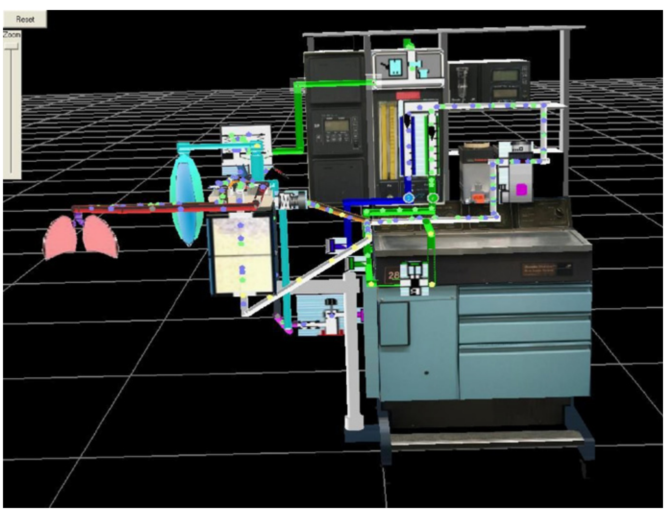

Fig. 2. The AAM visualization.

Fig. 3. A user views with the AAM visualization with a magic lens.

The research presented in this paper uses the AAM to demonstrate how MR can enable scaffolded learning and improve the overall understanding of a concept. Specifically, this paper describes:

1. The application of the augmented anesthesia machine [4].
2. A user study conducted to evaluate the AAM's scaffolded learning benefits.
3. Extending the virtuality continuum to classify technology-mediated scaffolding, such as the AAM.

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, in this section we 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 [5]. One approach to registration is to affix fiducial markers to the real objects in the scene and track them with a single camera, as implemented by ARToolkit [6]. Another approach consists of using stereo images to track retro-reflective IR markers [7]. To facilitate tracking and registration in the AAM, the system uses IR-based marker tracking for the magic lens.

2.2. Tangible user interfaces

A tangible interface [8] is an interface that employs real objects "as both representations and controls for computational media."[9] For example, a classic interface for a computer simulation is a graphical user interface (GUI) in which the user clicks on buttons and slider bars to control the simulation. The main purpose of a GUI is interactive 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 [10]. 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 created originally as 2D interfaces [11]. 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 [12]. Instead of using squares and circles to affect the underlying data on a 2D