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Virtual Terrorist Attack on the Computer Science Building: Design and Evaluation of a Research Methodology

Abstract

This paper describes the design and initial evaluation of a virtual environment and associated research model for the examination of affectively intense learning. The environment is a virtual computer science building on a university campus, which includes a number of affectively intense effects, such as explosions, fires, and interactive tools for controlling these events. The research model is based on the assumption that effective learning in these types of environments will occur with high levels of perceived affective intensity, presence, and knowledge acquisition. An initial evaluation of the environment and research model was carried out with five participants, within the context of a terrorist-attack scenario. The results indicated that both physiological and behavioral responses corresponded to affectively intense events in the environment, and that the environment and model can serve as effective tools for the systematic exploration of affectively intense learning with virtual environments.

Keywords

Virtual Reality, Learning Technologies, Affectively Intense Learning

1 Virtual Reality in Education

Virtual and Augmented reality environments have been used as tools for education and training in many settings in areas including industry (Miyakawa, Sugiat, Hashimoto, Fukamachi, & Shibata, 2000), the military (Hays & Vincenzi, 2000), and schools (Roussos et al., 1999; Salzman, Dede, Loftin, & Cheng, in press). Given advances in technology, and the need for new and creative tools to facilitate learning, it is no wonder that there have been an increasing number of applications of virtual environments as a learning tool.

Unfortunately, there has been much more development than evaluation. One exception was a recent report by Salzman and colleagues (Salzman et al., in press). This paper reported on a series of evaluation studies on the ScienceSpace virtual environment. ScienceSpace consists of virtual worlds designed to teach children complex abstract physics and chemistry concepts in NewtonWorld, MaxwellWorld, and PaulingWorld. This project constitutes one of the most ambitious and creative uses of virtual reality for learning. In cases where an outcome comparison was made, and inferential statistics were applied, results on the efficacy of the system were mixed in terms of pre-post test gains and comparisons with non-immersive systems. The results of other comparisons of Virtual Reality versus other learning methods also fail to find a consistent advantage for Virtual Reality environments (Moreno & Mayer, 2002).

This lack of efficacy evidence is due, in part, to a lack of systematic examination of the component factors that make up VR environments and their impact on learning. This has resulted in a general lack of knowledge as to what factors are most important for learning, and how these are mediated by other important variables such as the learner and the desired outcomes. At the outset of their report on their review of ScienceWorld, Salzman and colleagues noted that:

"Designers and evaluators of immersive virtual reality systems have many ideas concerning how virtual reality can facilitate learning. However, we have little information concerning which of virtual reality's features provide the most leverage for enhancing understanding or how to customize learning (Salzman et al., in press)."

One exception to this lack of systematic investigation of factors that account for effective learning in a virtual environment is a series of studies conducted by Winn and colleagues. Of particular interest were studies that focused on the evaluation of virtual environment called "Virtual Puget Sound" (Fruland, 2002; Winn & Windschitl, 2001; Winn, Windschitl, Fruland, & Lee, 2002), in which students interact with an aquatic virtual environment in an effort to learn basic earth science-aquatic principles. Although these studies did not consist of a comparison of VR with non-VR environments, they did focus on evaluation of characteristics of the VR environment that enhanced learning. Some of the factors that enhanced learning were: a) degree of emersion (those who wore a head mounted display performed better than those using a computer monitor); b) perception of presence (those who perceived a higher degree of presence performed better; and c) those who spent more time interacting actively with the environment performed better. One important caveat is that the positive impact of emersion was only seen for knowledge that involved understanding of dynamic 3-d concepts.

Our goal is to extend the research on efficacy of virtual reality as a learning tool, and on factors that mediate this efficacy, by focusing on affectively intense learning.

2 Affectively-Intense-Learning Research Model

Virtual reality is often used as a training tool for tasks that are to be performed in stressful environments, where emotions are likely to run high, such as military training (Bennett, Schreiber, & Andrews, 2002; Hays & Vincenzi, 2000), and, recently, as a tool for training in emergency situations for first responders to weapons of mass destruction (Tichon, Hall, Hilgers, Leu, & Agarwal, 2003). We refer to this type of learning as affectively intense learning (Tichon et al., 2003). Clearly this important type of training requires more than a traditional classroom approach. The goal is for the learner to perform in an environment where ability to perform under high stress conditions is paramount. Therefore, the training needs to reflect this as much as possible. However, developing a full-scale, realistic, simulation within a physical environment can require an overwhelming amount of resources. Moreover, such physical-environment-based simulations are generally costly and do not allow for easy modification. On the other hand, a virtual environment can be created, which provides realism and emotional intensity necessary for this type of training. Further, these environments do not have the same logistical demands; training is easily repeated, and various modifications to the training environment can be readily integrated.

We have developed a research model in order to systematically examine factors that will lead to effective, affectively intense learning. A fundamental assumption of the model is that the effective learning of these types of tasks will occur when three conditions are met: a) The learner feels a high degree of affective intensity; b) The learner feels a high degree of presence; and c) The learner acquires adequate levels of target knowledge. According to the model, if these three conditions are met, effective learning of affectively-intense tasks will occur. Figure 1 is a graphical depiction of our research model. We will begin our discussion of the model with the outcome and learner variables, followed by the virtual environment.

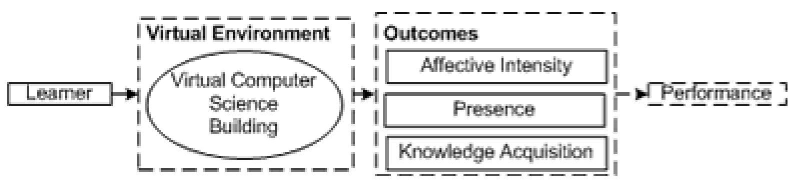

Figure 1. Research Model.

2.1 Outcome Variables

Psychologists have long known that the emotional congruence of learning and performance is an important factor in determining the learning effectiveness (Ellis & Moore, 1999; Schwarz, 2001). Therefore, an important component of our research methodology is the measurement of the degree to which the learner experiences the environment as affectively intense. We will measure stress responses via galvanic skin response (GSR), which is a measure of skin conductance. Moisture on the skin is an indication of sympathetic nervous system activity, and has often been used as measure of perceived stress in similar research (Jang et al., 2002; Meehan, Sharif, Whitton, & Brooks, 2003).

The most commonly cited VR outcome criterion is "presence". Though there has been much debate as to the exact meaning of the term as it applies to virtual reality, there is general agreement that it involves the degree to which the user experiences a feeling of "reality" within the virtual world – the degree to which the user feels that the world is NOT mediated by a technological interface (Schuemie, Vanderstratten, Krijn, & Vandermast, 2001). Although presence is sometimes measured via psychophysical (Wiederhold, Davis, & Wiederhold, 1998) and behavioral (Sheridan, 1996) indices, it is generally measured via survey instruments (Schuemie et al., 2001), since it is generally believed to be a matter of subjective perception (Sheridan, 1992).

Although there have been a lack of empirical studies of virtual reality and learning outcomes, there have been a number of such studies that have found a relationship between VR components and the perception of presence (Axelsson, Abelin, Heldal, Schroeder, & Widestrom, 2000; Barfield, Baird, & Bjorneseth, 1998; Freeman, Avons, Meddis, Pearson, & Ijsselsteijn, 2000; Schuemie et al., 2001; Slater, Sagadic, Usoh, & Schroeder, 1998; Thie & Vanwijk, 1998; Welch, Blackmon, Lie, Mellers, & Start, 1996). Unfortunately, studies that have measured both learning outcomes and presence have failed to find a relationship between the two (Mania & Chalmers, 2001; Moreno & Mayer, 2002). However, the lack of a significant relationship between presence and learning in these studies may be due to the fact that the target tasks were performed in affectively neutral environments. In the case where the task to be learned is to be performed in an affectively intense environment, the degree of presence during training will presumably play a strong role in mediating subsequent performance. It's important to note that, although measures of skin conductance are sometimes related to the perception of presence (Meehan, 2000), skin conductance and other measures of autonomic activity are measures of arousal not presence. In fact, sometimes factors that increase arousal decrease perception of presence (Schuemie et al., 2001).

In addition to measures of affective intensity and presence, a research program on virtual environments as training for affectively intense tasks certainly needs to include measures of knowledge acquisition. Of course, traditional tests of knowledge acquisition are not direct measures of performance within the real environment. However, the model assumes that knowledge acquisition within the virtual environment, combined with a high level of presence and affective intensity will serve as a reasonable indication of performance in the "real" environment.

2.2 Learner

Learner factors, of course, play an important role in all types of learning. With respect to virtual environments, it appears that an individual brings with them some tendency to experience presence before they even enter the environment. The Immersive Tendency Questionnaire (ITQ) (Witmer & Singer, 1998), was designed to measure this individual propensity and will serve as an important component of the proposed research model. The ITQ consists of subscales that measure a user's tendency to become involved in an activity (involvement), the ability to concentrate (focus), and frequency with which the user plays computer games (games). This measure predicted the perception of presence across two experiments (Witmer & Singer, 1998). However, the relationship between individual differences and empirical measures of learning outcomes associated with virtual environments has been largely unexplored.

2.3 Virtual Environment: Computer Science Building

A research program on affectively intense learning requires a prototype virtual environment. We identified a number of criteria that were necessary for such an environment. The environment should: 1) be able to provide high levels of affective intensity; 2) be able to provide high levels of presence; 3) be easily modifiable, such that specific environmental factors can be systematically varied, while other factors are held constant; 4) provide a relevant and realistic context for participants who are readily available via our research pool: undergraduate students; and 5) be able to support a learning scenario, with important implications for affectively intense learning as it occurs in "real world" situations.

A virtual environment modeled after the computer science building at the University of Missouri – Rolla was created, which addressed these criteria. The building, which was initially created for virtual campus tours, was modified in order to serve as a prototype for a project funded by the U.S. Army's Tank-Automotive and Armaments Command (TACOM, grant # DAAE07-02-C-L068) entitled "Advanced Virtual Environments for Training First Responders to Weapons of Mass Destruction", also referred to as the FiRSTE project (First Responders Simulation and Training Environment). The environment was further modified so that it could serve as the foundation environment for a research program on affectively intense learning.

The environment, created using the Half Life? game engine, consists of a four floor building, which includes classrooms, offices, and computer labs with the appropriate furniture, computers etc. For the affectively intense modification of the environment, loud explosions, which generate fires, were added. These explosion/fires are generated at random with the constraints that there are an average of three per minute, and the explosions go off in the general vicinity of the user. The building also includes two fire extinguishers and fire alarms on each floor. The user can acquire the fire extinguishers and use them to put out fires, and can also set off alarms. There is limited fuel in each fire extinguisher, and a user can "die" if he/she is too close to a fire for too long. Both of these factors are modeled in the environment, in that another fire extinguisher must be acquired when one runs out of foam, and a user cannot move for thirty seconds after losing too many health points from being too near a fire for too long. An additional feature of the environment is that users can turn on and off lights in the rooms. Figure 2 is a screen shot from the environment.

This environment has the potential to meet the criteria cited above in the following ways. The environment should be able to generate high levels of affect, through the loud explosions and fires, combined with the "danger" to the user and constraints on the equipment he/she uses to combat the situation. High levels of presence can be achieved through the realistic presentation possible with the game engine, and the use of an environment that represents a real physical environment with which undergraduate participants will be familiar. The Half Life? engine makes it easy to modify components of the building or add entities. The physical environment is realistic to participants in the subject pool at UMR, or similar universities, where there are class buildings including classrooms, computer labs, and offices. Finally, the environment can serve as a vehicle for affectively intense, relevant scenarios such as a terrorist attack. In the pilot study described here, we used such a scenario, which is described in the research method section below.

Figure 2. Screen Shot of Computer Science Building Virtual Environment with Explosion and Fire Extinguisher.

3 Pilot Evaluation Experiment

3.1 Goals

In order to evaluate our research methodology and tools, we carried out an exploratory experiment with a small number of participants. The two main goals of the experiment were to: 1) Determine whether measures of perceived affective intensity corresponded with affectively intense events in the environment, through quantitative comparisons of GSR responses, mean responses to the presence questionnaires, qualitative observation, and participants' self report; and 2) Identify methodological problems and/or other issues involving the efficacy of the research environment, via collection of qualitative data through observation and participant self-report.

3.2 Research Method

Five participants completed this experiment, three female and two male. Four of the five reported little experience with computer games, such as those that utilize the Half Life? engine. All participants were UMR undergraduate students, with the exception of one male subject who was a computer science professor (not affiliated with the research project).

Participants completed this experiment in the University of Missouri – Rolla's Human Computer Interaction Research Laboratory's usability facility. The facility consists of two cubicles, one for the participant and one for the researcher. The participant's computer screen is dynamically recorded, and facial expressions are recorded via a video camera. Such a set up is fairly typical of modern usability laboratories, with the exception that there are no one-way mirrors, nor additional observation rooms (Barnum, 2002). In addition, galvanic skin response was recorded using BIOPAK? software and hardware. The data collection device consists of two Velcro strips that are wrapped around two fingers on the participant's non-dominant hand. The facial expressions, video capture of the game, and the Biopak readings are synchronized via a mixer and stored as pictures-in-picture on videotapes, for use for qualitative observation. A screen shot from one of these videos is displayed in Figure 3. The computer that ran the virtual environment was a two-year-old PC with an 800MHz Pentium 3 processor, 256 MHz of RAM, and a standard integrated graphics card.

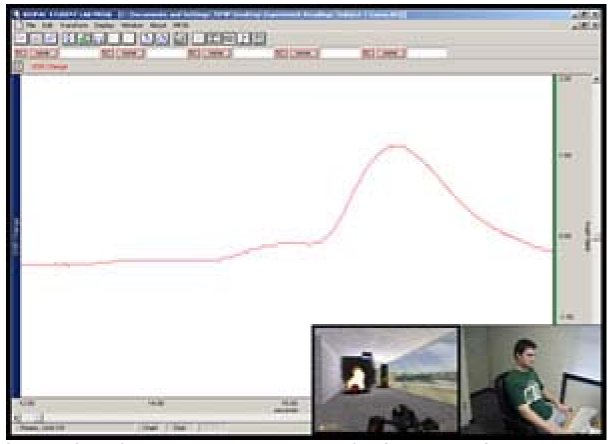

Figure 3. Screen Shot from Usability Video used for Qualitative Observation Review

After being briefed on the nature of the experiment, and completing a consent form, the GSR measuring device was attached to participants' non dominant hand and, after it was determined that the device was reading correctly, a two minute baseline recording was taken. Following the baseline recording, participants completed the immersive tendencies questionnaire (Witmer & Singer, 1998). They were then provided with written directions for operation of the virtual environment, after which the practiced in an acclimation environment for five minutes, which included two rooms and all of the controls they would be required to use in the testing environment, without the explosions and fires. Note that all of the controls in the virtual environment were carried out via a five-button mouse, since participants were wearing the GSR measuring device on their non-dominant hand.

Before beginning the testing phase, participants were required to read the following, which includes the training scenario and task requirements:

"Scenario: The year is 2003. It is two years since the gruesome attack on the World Trade Center. Today it is happening again, this time – the target is an educational institution. It was apparently easy to take over due the relaxed security in a campus environment; the consequences can be devastating.

"The University of Missouri – Rolla is suddenly faced with a situation. The computer science building has been taken over by terrorists. The only information received on the situation is that the building has been booby trapped with explosive devices. Police arriving at the scene managed to kill one of the members of the operation during an attempt to escape, the remaining managed to flee. The death toll is put at 4 dead including 3 graduate students and a professor. The building has been cordoned off and is off-limits until your team of first responders can defuse the situation.

"According to the latest reports, there are no terrorists remaining in the building. But the fires and explosions continue to rage. This situation needs to be neutralized. You are a first responder- primary profession – fire fighter. It is your responsibility to enter the building, to check the different floors for any possible threats, and eliminate them.

"Experiment directives:

1. Move around in the VR environment of the computer science building. Explore all three floors.
2. Enter marked doors (those that have numbers) and turn off the lights.
3. On event of fire:
    a. locate the nearest fire alarm and set it off;
    b. locate the nearest fire extinguisher and pick it up (if you aren't already carrying one)
    c. put out the fire.
4. At the end 10 minutes the experimenter will give you a signal and you should exit the building as quickly as possible.

"Note:

- The fire extinguisher has a limited amount of foam, so once it is empty a new one must be located. (A counter on the lower right of the screen will indicate amount of foam remaining).
- Fires grow rapidly, so it is advised to put them out quickly. If you are exposed to the fire too long – health points are reduced, the health monitor, located on the lower left, on reaching 0 will result in a 30 second "death" period during which time you will be unable to move. Therefore, exercise caution when approaching fires."

After reading these directions, participants carried out these tasks in the testing environment for ten minutes. After the testing activity, participants completed the presence questionnaire (PQ) (Witmer & Singer, 1998). Finally, they were asked to provide comments on their experience in general, with an emphasis on information that would aid us in improving our research methodology.

3.3 Results

3.3.1 Quantitative Analysis

In order to address the first objective, which was to determine whether measures of perceived affective intensity corresponded with affectively intense events in the environment, the GSR measure was broken into three parts: baseline, explosion, and non-explosion. In all cases GSR was sampled at a rate of 20 times per second. The baseline measure simply consisted of the mean of the sampling data over the course of the two-minute baseline recording. In order to derive a GSR measure associated with explosions, we began by examining the GSR data in conjunction with the explosion timeline, and noted that, in all cases, there was a GSR peak that occurred within 4-6 seconds after an explosion. Based on this, we decided to define an explosion section as beginning with the steep incline at the beginning of the peak and ending with the steep decline following the peak. This is illustrated from sample data in Figure 4. The average of the 20 samples per second for a given explosion sections, served as the basic unit of data for explosion sections. The average of the 20 samples per second for each time period between explosion sections was used as the basic unit of analysis for non-explosion sections. To provide us with some sense of changes over the course of training, we grouped all of these section means into four groups representing each quarter of the time participants played the game. There were approximately ten explosions for each quarter. Finally, in order to more accurately display descriptive GSR readings, every sectional mean was represented as a change from baseline, by subtracting the sectional mean from the users' baseline mean.

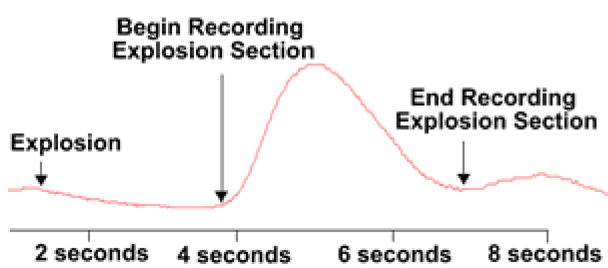

Figure 4. Sample data illustrating explosion/peak relationship.

Since the number of explosions differed slightly for each participant, the total number of section means (difference scores) differed slightly. (These ranged from 58 to 76 data points total for the different participants). Also, within each section, and within each explosion type (yes vs. no) the number of section means differed slightly. In order to make the data points equivalent for all participants, we decided to include seven explosion and seven non-explosion section means for each participant for each quarter. We used seven, because this was the median number of explosions per section per quarter, and this also allowed for each participant to have a data point for almost all section means considered. In the case, where there were more than seven section means for a given participant for a given quarter, the first seven were considered and in the few cases where there were less (3) the additional data was considered missing. This resulted in a 4 (quarters) x 2 (explosion level) x 7 (section means) matrix, which was used for the analysis.

We used these data to computer a three-way repeated-measures analysis of variance with quarters (1 through 4), explosions (no vs. yes), and unit (1 through 7) serving as within-subject factors. The main effect for explosion was marginally significant $F(1, 2) = 12.77$, $p = .07$, $eta^2 = .87$. No other effects were significant. The mean of the difference score means for each quarter for explosions and non-explosions are displayed in Figure 5.

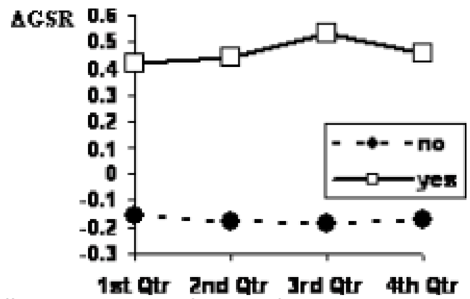

Figure 5. Mean GSR difference scores as a function of test quarter and explosions (yes vs. no).

Mean scores on the Immersive Tendencies Questionnaire (IMT) and Presence Questionnaire are displayed in Tables 1 and 2. The scores are presented as a percentage of the highest score possible, with higher scores represented higher degrees of immersive tendency and presence (negative items were reversed in scoring as appropriate). The scores are also broken down by subscales in the tables. The subscales for the ITQ represent the following: focus (an individual's tendency to maintain focus on current activities); involvement (an individual's tendency to become involved in current activities); and games (an individual's tendency to play video games). The subscales for the presence inventory are: auditory (the degree to which auditory factors enhanced presence), involvement/control (degree to which individual felt he/she could control and become involved in events), natural (the degree to which the environment felt natural), interface quality (the degree to which the visual display enhanced presence); and resolution (the degree to which the user felt he/she could examine objects in detail) (Witmer & Singer, 1998). (There is also a subscale that represents the degree to which haptic quality added to presence. However, since this virtual environment did not include any haptic components, items associated with this subscale were removed.)

Due to the small number of participants, no inferential statistical analyses were performed on these scores.

SUBSCALE	MEAN SCORE (percentage)
Focus	64.39
Involvement	48.16
Games	32.86

Table 1. Mean scores on Immersive Tendencies Questionnaire Subscales

SUBSCALE	Mean Score (percentage)
Auditory	66.67
Involvement	61.43
Natural	49.52
Interface Quality	54.29
Resolution	45.71

Table 2. Mean Scores on Presence Questionnaire Subscales

3.3.2 Qualitative Analysis

The following is a summary of points that emerged from examination of user's self report and observations of users during the sessions and post-hoc observations of videos.

- One subject was left handed, which made it very difficult to maneuver with a right-handed mouse.
- Facial expressions and body movements indicated moderate to intense degrees of presence and response to affectively intense stimuli as participants shifted in their seats in response to on-screen stimuli. These behavioral responses tended to mirror GSR responses.

- High GSR readings and behavioral responses also occurred when participants got frustrated, such as when they were unable to locomote effectively, such as one participant who turned off a light and then could not turn it on, and could not leave the room for some time.
- Some participants commented that the graphics were slow and unresponsive.
- Despite the fact that most participants had little experience with computer games, most were able to carry out required tasks reasonably well.
- Some participants noted that they recognized rooms where they had classes, and one student found this environment so realistic that he was reluctant to put out the fires because "I never much liked the computer science building anyway".
- The one subject who had experience with video games noted that having all controls on the mouse was counterintuitive.

4. Conclusions

The quantitative analysis of GSR levels indicated that arousal levels were dramatically higher following affective events (explosions) in the environment as compared to the rest of the time participants were in the environment. The difference was only marginally significant ($p = .07$), but this most likely due to the lack of statistical power, given that the size of this effect was strong (eta square = .87). An examination of the means across quarters indicates a that the means for the explosion sections did not decrease during the course of the experiment (Figure 5). This indicates that the perceived intensity was strong enough that users did not habituate to the explosions over the course of the ten minutes they spent in the testing environment.

No statistical analysis was possible with immersive tendency and presence scores due to the small number of participants. However, observation of the means does indicate some interesting trends. With respect to immersive tendencies, as indicated, most of the participants in this pilot study had little experience with video games, though tendencies toward a high degree of focus and moderate degree of involvement were indicated. This was reflected in the qualitative analysis, which found users to often appear highly involved and present. The means for the subscales of the presence inventory indicated that, over all, users tended to perceive reasonably high levels of presence. The highest degree of presence appeared to be the result of the visual and auditory cues, combined with the degree of involvement users felt with the game. The latter may well be the result of the terrorist scenario that provided the context for the testing session. The degree to which the resolution enhanced presence and the degree to which the environment was perceived as natural constituted the lowest presence scores. This is at least partially relates to users comments that the graphics were relatively slow and unresponsive, which was the consequence of a relatively old PC with a slow processor and poor quality video card.

The qualitative results indicated that users observed behavior was largely consistent with the quantitative measures, in that users responses to the explosions were evident, and their facial expressions and body movement were indicative of a moderate to intense degree of presence. The qualitative analyses also uncovered some methodological and logistical issues that will need to be corrected for future experiments. First, a left-handed mouse should be available for left handed participants. Second, a more powerful PC should be used in order to provide the user with a more responsive environment.

Overall, these results indicate that the research model and tools should provide an effective foundation for a research project aimed at exploration of affectively intense learning with a few relatively easy modifications. The next step is to begin examining factors that will contribute to effective learning in these types of environments. Among the factors to be considered are: a) degree of immersion (using head mounted displays and other external devices); b) guidance and dynamic assessment (providing the user with guidance and feedback); and c) collaboration (exploring the impact of a multiple users).

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