Factors Impacting Virtual or Augmented Reality Effectiveness in Training and Education

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ABSTRACT

Numerous advances in virtual and augmented reality (VR/AR) technologies have made them far more accessible and affordable than ever before, and as devices proliferate, they have taken different approaches to realism, immersiveness, interactivity, and emotional connection to the user. With so many options to choose from, it is important to examine whether these technologies and applications have a measurable impact on learning outcomes when compared to traditional methods. This paper examines specific elements of VR/AR to help quantify their impact on learning outcomes and whether their effectiveness changes based on different applications, creating a framework based on a combination of focus area, educational goal, focus level, and system interconnectivity in a format similar to a Meyers-Briggs personality test. This framework should assist decision makers maximize their return on investment by illustrating which VR/AR features are most effective based on the type of curriculum.

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INTRODUCTION

As Virtual Reality (VR) and Augmented Reality (AR) systems become more capable and accessible, they are increasingly promoted as having the potential to revolutionize training and education programs. However, systems vary in just about every way: size, scope, cost, realism, etc. With so many choices, it can be difficult to cut through the marketing to understand what features will have a significant impact on student outcomes in different training programs. Additionally, there is no one-size-fits-all approach for all types of applications. Not only are there differences between traditional classroom schools and more hands-on vocational training, but there are different curriculum approaches to consider, such as whether the goal is to teach new knowledge or skills, or to see if the student can apply those skills in the real world. Finally, depending on the specific application, the type of training will vary widely, as a manager needs vastly different training and requires different skillsets than a pilot.

When it comes to VR/AR applications, most of the attention focuses on applying VR/AR solutions only in specialized situations requiring realistic simulations for training purposes. However, those applications only address a small portion of possible use cases. There are many additional potential applications ranging from mechanical maintenance, to cyber warfare, to leadership and decision-making skills. As more applications are explored, decision makers must ensure any increased use is grounded in solid pedagogical reasoning, rather than the belief that students would be motivated by the novelty of the technologies. VR/AR systems are not a panacea for all training and education needs; rather, they are tools that have the potential to improve student outcomes when appropriately and deliberately integrated into the training curriculum. Throwing technology at a problem without sufficient evaluation will only result in additional expenses; the appropriate technology features must be paired with the right teaching objectives to achieve a solid return on investment and optimum student learning opportunities.

LITERATURE REVIEW

Key Features of VR/AR

Before looking at ways to apply VR/AR, it is important to first define what makes it different than other learning experiences. There are three general categories that are frequently mentioned in the literature: immersion, presence, and engagement/interactivity (Mutterlein, 2018). These three factors influence each other and have an overall impact on the user's experience and learning outcomes. There are a couple of challenges when trying to study whether immersion, presence, or engagement have the most effect on learning outcomes. The primary challenge is there often overlap in the way different researchers use the three factors, so while one paper may report a correlation between presence and improved learning, another paper may use similar criteria but call it engagement or immersion. This is partly due to the fact that although there is some general agreement in the literature on how categories are defined, the lines between them are blurry. Additionally, because the three categories both rely on and influence each other, it is challenging to separate them into discrete elements. For the sake of clarity, the way the three terms are used in this research are defined below.

Immersion

While immersion and presence sound like similar attributes, immersion in this context describes the technology. It represents the extent to which the system can deliver an environment that a user can feel like they are a part of. Slater and Wilbur defined four elements that influence the level of immersion that a system provides: inclusiveness, extensiveness, surrounding, and vividness (1997). Inclusiveness addresses the extent to which the real world is shut out, which may or may not be a necessary goal for the system. For example, in a 100% VR environment, awareness of the real world can be distracting to the user, but in an AR environment, the goal is to seamlessly integrate the experience with the real world. Extensiveness refers to the range of sensory modalities accommodated, such as whether the system is visual-only, incorporates sound, or provides tactile feedback from touching virtual objects or producing vibrations. The surrounding element covers the extent to which the visuals within the system are panoramic, rather than limited to a narrow field. This could take a variety of forms, from a large, dome projection screen to a helmet-mounted system. Vividness describes the richness, resolution, and quality of the displays. These elements of immersion do not exist in isolation, as design decisions around one dimension can force changes in others. For example, a desire to make a system highly inclusive would likely drive design changes to improve the surround element to reduce chances of seeing the real world.

An additional variable that impacts immersion is plot. This is the extent to which the system presents a storyline that is self-contained, has its own dynamic, and provides an alternate unfolding sequence of events, quite distinct from those currently going on in the real world. Much like how a person can lose themselves in a good movie, if the system has a plot that does not make sense in the context of the simulation, the user will have a difficult time immersing themselves into the simulation. This does not mean the system must be true to real life, but rather that the system must allow the user to interact with the environment, influence events as they unfold, and effect changes to the virtual world in a way that is internally consistent (Slater & Wilbur, 1997).

A key decision point for the developer is how far to take those elements to replicate the real world in the virtual environment. Of course, the better the realism, the more difficult and expensive it will be to implement. Accurately matching movement and vision requires some degree of body and head tracking, so that as a user turns their head there should be a realistic change to the visual display and auditory inputs so that sound direction corresponds to the orientation of the head. Other aspects of matching include minimizing lag between physical actions and the corresponding system response and adjusting visual cues such as shadows to reflect changing light patterns based on the person's viewpoint. Immersion essentially provides the technical boundaries within which a person can establish their sense of presence. Any virtual system will always have limits beyond which it will not be able to maintain its immersion. It is a delicate design balance, because on one hand the more capable the system is and the more freedom the user has probe the boundaries of the system, the more immersive and realistic the user will find the experience to be. But on the other hand, increasing capabilities drives higher cost and technical complexity. Additionally, the more freedom a user has to probe any system, the greater the chance that they will hit a boundary or condition not envisioned by the developers (Slater, 2009).

Presence

Whereas immersion is a quantifiable description of a system's technical capabilities, presence refers to the user's sense of being in the virtual environment (Slater & Wilbur, 1997). It is a complicated concept to objectively measure, as presence is a multi-dimensional subject that is typically an umbrella term for many inter-related perceptual and psychological factors (Kalawsky, 2000). It is important to note that presence differs from belief. Presence is the illusion of being there, even to the point of experiencing physiological reactions, even though the individual knows they are not really in that situation. The concept is the same as when people jump or feel their heart pound when watching a scary movie. The person knows what is happening on screen is not real, but by the time the cognitive system catches up to remind them that they are not in any danger it is too late; the physiological responses have already occurred (Slater, 2018). The immersiveness of VR/AR has the potential to harness this effect, capitalizing on these phenomena to feel more realistic. That said, the relationship between immersion and presence is not a direct one-to-one relationship. Although the breadth and depth of the sensory experience is important in improving the experience, the basic appeal still lies in its content, storyline, ideas, and emotions that are being communicated. Presence is something established in the mind, and thus it is not reliant on any specific type of technology. Something as analog as a book, if sufficiently well crafted, can establish a sense of presence. In other words, presence has less to do with simulating physical reality and is more about how the mind perceives reality (Banos, et al., 2005).

With so many variables that can influence a user's overall sense of presence, Slater proposed two distinct types of illusion to attempt to provide more clarity on the different ways a user's sense of presence can be impacted: place illusion and plausibility illusion. As the name implies, place illusion "is the strong illusion of being in a place in spite of the sure knowledge that you are not there (Slater, 2009)," and it is specifically the user's subjective perception and not a measurement of the system's capabilities. Different users will have a different sense of place illusion despite using the same system, and that sense is going to be impacted by both their previous experiences and by their actions within the simulations. For example, one user may stay relatively static within a simulation, while another moves around and attempts to interact with different objects. In a less capable system, that person may hit boundaries that disrupt the place illusion. In a highly capable system, the active user may find the experience more enriching and realistic, strengthening this effect.

While place illusion is focused on how the virtual world is perceived, plausibility illusion refers to the user suspending disbelief and accepting that the illusion around them is actually happening (Slater, 2009). An example of the difference between the two is a study conducted by Pan and Slater, in which a male user is placed in a virtual scenario where he is approached by a female at a party (2007). The participant's sense of being at a party, seeing the people, hearing music, and having the field of vision move appropriately as they move their head is the place illusion. Their reaction when a virtual woman approaches them and starts a conversation, such as whether they feel embarrassed, experiences changes in heart rate, and engages in a conversation with her, is an example of plausibility illusion (Slater, 2018).

Engagement

Engagement is a multifaceted concept that refers to the combination of increased concentration, interest, and enjoyment that a student experiences (Hamari, et al., 2016). Fredricks et al suggest there are three different types of engagement: behavioral, emotional, and cognitive. Behavioral engagement is focused on participation and is considered crucial for achieving positive academic outcomes. Emotional engagement is tied to the willingness to do the work and is influenced by both the positive and negative reactions to the people, environment, or subject matter. Finally, cognitive engagement considers the thoughtfulness and willingness to exert the effort necessary to comprehend complex ideas and master difficult skills (Fredricks, Blumenfeld, & Paris, 2004). While they are defined as separate types, it is important to note that they are not isolated processes and are dynamically interrelated. Research by Pellas found the three were correlated in a game-based learning environment (2014).

Specific to virtual environments, the concept of using games to improve student engagement has been supported by multiple studies. Coller and Shernoff showed that undergraduate engineering students were far more engaged in homework and labs that were presented in a game-based format (2009). Likewise, a mobile multimedia game designed for History education also had a positive effect on student engagement (Akkerman, Admiraal, & Huizenga, 2009). This does not mean, however, that any type of gamification will increase student engagement. Similar to how a poor plot interferes with a person's plausibility illusion, the gaming experience has an impact on student engagement. Experienced gamers will have a higher expectation for the quality of a game, which means their gaming experience could moderate their level of engagement with educational games which will necessarily differ in focus from those purely for entertainment (Deater-Deckard, El Mallah, Chang, Evans, & Norton, 2014).

Effectiveness of VR/AR in Improving Educational and Training Outcomes

Before examining how VR/AR could improve student outcomes, it is important to first establish a firm understanding of the curriculum the VR/AR system would support, as the curriculum is the most fundamental part of any training program. Ornstein and Hunkins (2009) and Sowell (2005) break these elements down into three main categories of curriculum design based on whether the curriculum is viewed as a body of content that should be delivered in logical groups based on a specific subject-area (subject-centered); is designed around students' lives, needs, and interests rather than subject area (learner-centered); or focuses on placing the student in a scenario to solve real-life problems (problem-centered). Literature on VR/AR effectiveness largely skews towards simulations and training applications, which is typically part of a problem-centered curriculum. However, as technology continues to improve and become more accessible, research is starting to evaluate whether there is justification to use them as an alternative medium for widespread, non-specialized digital education. This research tended to focus on two areas: whether VR/AR could be applied in a traditional, subject-centered educational setting, or if they could be applied to automatically adapt to the student's needs in a learner-centered curriculum to help remove some of the resource burdens associated with that approach. All curricula are not the same, and depending on the application and desired learning objectives, different design elements, processes, and points of emphasis apply.

Subject-centered Curriculum

Research into the effectiveness of VR/AR in a subject-centered curriculum found generally positive results in a wide variety of potential applications. First, looking at traditional classroom education, several studies assessed whether the introduction of computer games positively impacted their students. The key takeaway from these studies was the importance of the game design to engage and challenge students. Challenge was an especially strong predictor of learning outcomes, and the perceived challenge of the game affected learning both directly from overcoming the challenge and indirectly due to increased engagement (Coller & Shernoff, 2009).

While immersion and presence certainly influence the student's level of engagement, results conflicted on whether they directly impacted student outcomes. For example, one study showed that engagement in the game had a significant positive effect on learning, but immersion did not (Hamari, et al., 2016). However, another study found that the more that players were immersed in the game, the better they performed in the game, but the improved game performance did not translate to better science learning outcomes (Cheng, She, & Annetta, 2015). A third study involving engineering college students found that students experienced higher intellectual intensity, intrinsic motivation, and overall engagement when working with virtual games compared with traditional approaches to homework and class work in mechanical engineering (Coller & Shernoff, 2009). Students not only felt active and interested, but also more creative and less worried due to the removal of typical classroom pressures.

This observation about how the students felt more interested and less pressure was found in applications that did not involve games, too. One study looked at the effect of adding VR to an online course teaching users how to identify potential safety hazards in a manufacturing environment. On one hand the study did not find significant differences in learning outcomes, but on the other hand the students perceived significant improvement, were more engaged in their learning, and found the systems overall to be more enjoyable (Madathil, et al., 2017). Another study that looked at teaching craftsmen skills also found that student enjoyment was significantly improved, even though students knew they also needed hands-on experience to fully learn their trade (Spilski, et al., 2019). These studies suggest that at a minimum, applications of VR/AR are at least on par with traditional methods when it comes to learning outcomes, and significantly improve the learning experience, which could have longer term benefits in keeping students engaged. They also show that VR/AR has the potential to be included into a wide range of subject areas, and more importantly, to be accepted by learners and teachers if done as part of a well-planned subject-centered curriculum.

Learner-centered Curriculum

Learner-centered applications present an opportunity for VR/AR deployment because, if designed correctly, VR/AR systems can adjust to the needs of each individual student to give them tailored instruction and problem sets to maximize their learning potential. One example of this application involved a game teaching the Medieval history of Amsterdam through the use of storytelling that used students to perform one of three different roles: construct the story as directors, participate in the story as actors, or receive the story as spectators as a control group. The game allowed instructors to perform facilitator roles, rather than needing to provide direct instruction to the students (Akkerman, Admiraal, & Huizenga, 2009).

Both constructors and participants saw significant improvement in student engagement, but there was an interesting difference in the way the two groups performed. The constructors had the best overall educational outcomes, as their feeling of being in control and having ownership of the activity drove both focus and engagement. Additionally, they had the ability to take a bird's-eye view of the teams they were directing, allowing them to see the big picture and context of the actions. For the participants, the activity was more intense than in constructing, as they were literally acting out the story and physically seeing the buildings and viewpoints of historical characters. By physically experiencing these narrative elements, they become more meaningful for the student. However, the focus of the students was also drawn to what was happening in real time on the street, which affected their overall sense of presence in the game. While trying to find their way through the city, searching for assignment locations and completing the assignments, students lost the sight of the overall structure of the game and its high level narrative (Akkerman, Admiraal, & Huizenga, 2009). These findings are consistent with other studies that found a negative correlation between emotional involvement and science-based learning outcomes (Cheng, She, & Annetta, 2015). Essentially, the individual interactions had more meaning to the students at the expense of the larger context.

Other studies also point to the importance of engagement. One study focused on teaching programming structures found that student behavioral engagement had a linear correlation with cognitive engagement and learning outcomes, as well as a positive association with emotional engagement in collaborative learning tasks. These results combined to show that keeping students on-task was significantly positively correlated with the expression of solutions in problem-based tasks and overall student satisfaction (Pellas, 2014). Outside of a gaming context, a VR/AR application allows students to build knowledge from a direct experience, rather than a description of the experience, since VR/AR allows for participants to interact with their environment similar to the interaction that takes place in the real world (Alfaro, Rivera, Luna-Urquizo, Alfaro, & Fialho, 2019). This action-oriented learning allows students to engage their curiosity with the subject matter, rather than focusing on earning a passing grade. If the simulation is designed to handle experimentation, this allows and encourages students to experiment and modify approaches to help them build knowledge through experiences.

Problem-centered Curriculum

Problem-centered curriculum is the most common application of VR/AR technologies, since they are easily applied to simulators and other scenario-based training programs. For simulations, immersion was shown to be an important aspect in engagement and improved learning outcomes, even if there was little attempt to establish presence. For example, one study had students observe a sequence of events within a complex geometrical structure and attempt to reproduce them. One group used an immersive virtual environment, while the other used a non-immersive virtual environment. The results showed that immersion tended to improve task performance, presumably because immersion improves comprehension and memory of the three-dimensional structures and the movement of the pieces (Slater, Linakis, Usoh, & Kooper, 1996).

When applied to problem-solving scenarios, simulations have an ability to really set themselves apart from other methods if designed well. This goes beyond flight simulators or other common applications, as the virtual environment allows students to put their skills to the test in an environment where they can make a mistake, learn from it, and repeat the scenario. In one example, a VR simulation was created for doctors to practice decision-making skills on trauma patients. Both instructors and participants reported strong enjoyment levels with the simulator and felt it was a cost-effective learning tool, and performance of the participants accurately reflected the differing skill levels between the instructors and students. Most of the participants also felt that practicing and maintaining trauma management skills on a VR simulator was important (Harrington, et al., 2018).

Design Elements

The review of the literature highlighted several positive and negative aspects of VR/AR that were common across the board, and thus should be considered in the design of a VR/AR solution. By far the most frequently reported issues related to poor system or scenario design. On the technical side, issues included counter-intuitive interfaces, confusing objectives, inaccurate representations, limitations with the input hardware, and even getting lost in the virtual environments. In terms of scenario issues, students frequently reported the lack of realism provided by the educational VR implementations and a lack of engaging content (Kavanagh, Luxton-Reilly, Wuensche, & Plimmer, 2017). This illustrates that a VR/AR system cannot be designed and implemented without being well thought out from both technical and curriculum angles. Without both pieces, the best result is either a fantastic looking simulation with little training or educational value, or a system that potentially detracts from excellent content because it is distracting or not user friendly. If either the system or the curriculum is insufficient, the student will not be properly engaged, but if both are done as part of a holistic curriculum, VR/AR holds significant potential.

Another identified best practice is providing pre-training to students and instructors. In one study, a group that was not given pre-training appeared overwhelmed from learning both the VR system and educational content. Another group that was provided pre-training, even though it was basic material, experienced a more immersive VR experience because they were not distracted by the VR system's mechanics (Meyer, Omdahl, & Makransky, 2019). Pre-training can also be used to set student expectations for the simulation, as instructors can cover not only the technical boundaries of the system, but also explain which concepts are being covered by the system and which concepts will be covered with other methods so students do not assume the system is meant to be all-inclusive.

This also means that the simulations do not need to be hyper-realistic to be effective teaching tools, suggesting several technical elements that should be considered as part of the system design. Especially when the objective is to learn new skills rather than demonstrating a skill in a simulator, the immersive experience can distract from the learning task if taken too far (Jensen & Konradsen, 2018). The key is for the developers to find the optimal balance, as other research has shown there is certain level of immersion that produces significantly better training outcomes than a non-immersive environment, especially when visual skills are being taught (Vora, et al., 2002). Designers need to also balance other variables such as the enjoyment of the game and the curriculum. Cheng et al. (2013) found that the more the players feel the game is playful and enjoyable, the less they learn, as players become more immersed in the game and not the educational content. Similarly, invoking an emotional reaction in the user can improve their sense of presence and engagement, but it can also distract from the learning. However, depending on the use case, this is not necessarily a bad thing. Leveraging emotion can be a powerful learning tool if the scenario is focused on soft skills, crisis management, or therapy, but it could be a distraction when learning physics. The is also some evidence that creating some level of stress or frustration by inserting non-player characters that provide erroneous information or by embedding conflicts and discrepant events can improve learning as students need to confront a problem and find solutions (Cheng, Huang, & Hsu, 2019).

Above all, the most consistent design feature to improve student outcomes was applying the appropriate amount of challenge. Multiple studies found the challenge created by games were an important antecedent for engagement and essential for learning through the game (Hamari, et al., 2016). VR/AR, especially when used as a game, affords a great deal of individualized customization in terms of matching the challenges of the learning activity to a player's skills as they progress. Results imply that the challenge of effective educational game design is for games to keep pace with the learner's growing abilities to facilitate continued learning in game-based learning environments. This can continuously keep players engaged in learning, helping students who may get bored or overwhelmed during traditional instruction stay active and motivated. Optimistically, this could result in the development of games that are adaptive and customizable for a broad and diverse audience of learners. These findings suggest that game designers should emphasize challenge and engagement while considering players' skills, which were found also to contribute to engagement and immersion (Hamari, et al., 2016). Other universal design elements include practical considerations such as curriculum support (how much guidance and supporting materials will be provided to instructors), scalability (whether this is a niche use case or if need to be able to expand), sustainment (how scenarios and technology will be maintained and updated), and the volume of students (how many systems are needed at one time).

In all, the key to using a game as a teaching machine is not its immersive 3-D graphics, but its underlying architecture. The best games adjust to the player's skill level, so that each level sits at the outer limits of the player's abilities, seeking at every point to be hard enough to be just doable. Few educational games keep pace with contemporary entertainment titles and thus fail to achieve this potential. Fewer resources are spent on their production, and they are developed without attention to what makes games compelling (Squire & Jenkins, 2003).

METHODOLOGY

In order to examine the different requirements that a VR/AR system needs to be most effective in different types of curricula, a framework was developed that established four different categories to describe a given curriculum: focus area, educational goal, focus level, and interconnectivity. Within each category are two different options to describe the curriculum's approach to that category, resulting in sixteen possible outcomes similar in approach to a Meyer's Briggs personality test to mirror a familiar layout. The specific design features that each outcome should focus on are described and summarized in Table 1.

Framework Categories

Focus Area: Subject-Focused (S) vs Learner-Focused (L)

This category addresses whether the curriculum is Subject-Focused (where the learner adapts to the material) or Learner-Focused (where the material adapts to the individual learner). These categories are similar, but not identical to, the types of curriculum design discussed in the literature review. The impact of a problem-centered curriculum design type is captured in a later category within this framework, as a problem-centered curriculum could be either focused on a specific subject or on a specific student.

The goal of a Subject-Focused environment is to effectively guide students along a set curriculum, rather than allowing students to choose their own learning pathway. This means the VR/AR system should focus on consistent content delivery to ensure each student receives the same instruction. If the material is presented in a game format, the game would require the user to complete a specific mission or set of tasks before they can proceed further in the game. In other words, what the student needs to do is pre-determined, and the student learns by practicing or figuring out how to do it in a prescribed order. In this type of Focus Area, engagement is more important than immersion or presence. Although immersion and presence play a part in engagement, they could potentially distract from the subject matter if taken too far. This also means that primary way the students are engaged is through actions they must take, rather than focusing on making an engaging scenario. Because they have the most direct impact on fostering engagement, the most important game elements contributing to Subject-Focused environments are plot design and the challenges presented. In a Learner-Focused environment, the goal is to allow the student to choose the order in which they interact with topics within the larger context of the curriculum. In the video game analogy, this would be an open-world format, where the player is free to decide for themselves what tasks or missions they want to tackle to progress in the overall story. For this application, designing the system to produce an adaptable, interactive scenario is critical for students to establish presence and be encouraged to explore.

Educational Goal: Skill-Based (K) vs Application-Based (A)

The Educational Goal category determines whether the goal is to have the student learn and demonstrate a new skill, versus utilize skills they already have to solve a problem or navigate a scenario with no immediately obvious solution. Skill-Based examples include traditional classroom education where a student is learning a specific topic such as a cyber security student learning how to configure a firewall, or vocational classes such as teaching a beginning pilot the specific skills and techniques to fly an aircraft. Application-Based examples for those two students would include tasking the cyber security student with hardening and successfully defending a network, or having the pilot fly a complete sortie and respond to various issues and emergencies during the flight.

Skill-Based goals involve the same general concerns as the Subject-Focused curricula, where student engagement is the most important aspect. Because repetition and other practice drills are needed for the student to gain proficiency in the desired skill, engagement helps maintain student interest and effort, preventing boredom and disengagement. Immersion and presence should only be applied to help enhance the engagement but should be limited to prevent distracting the student from the actual skill being taught. Other design considerations should focus on ensuring the specific skill is learned correctly, such as providing immediate feedback to correct mistakes, and making the scenario short enough to be easily repeatable. Conversely, Application-Based training is where immersion and presence play a larger role, as the intent is to make the user feel like they are actually experiencing the particular scenario being simulated. Rather than teaching the student a new skill, Application-Based training assesses whether the student can effectively apply the skills they have previously learned to a problem or scenario without the ideal solution being choreographed by learning objectives. As a result, increased presence is not distracting but instead benefits the scenario. The pressure, stress, and other distractions from increased presence helps mirror the real world and more accurately reflect the student's command of the subject matter. Thus, students should receive detailed feedback at the end of the scenario, rather than immediately during the simulation, to prevent interrupting their sense of presence.

Focus Level: Detail-Oriented (D) vs Big-Picture (B)

This category considers whether the curriculum is focused on details needed to perform a specific task or whether it is looking at larger goals or objectives. Detail-Oriented curricula focus on subject matter expertise and the utilization of small teams, whereas Big-Picture curricula help students synthesize concepts or utilize skills in pursuit of a larger goal. For example, detail-oriented training would be teaching an infantry squad the tactics to effectively patrol and secure an area, whereas big-picture training would teach how to recognize which tactics apply to a given situation or which teams and skillsets should be employed as part of a larger, more strategic military maneuver.

Detail-Oriented training requires the scenario to be as accurate as possible. For those learning new skills, generalizations that gloss over specific details can lead to students developing bad habits or otherwise not learning the precise skills they need. In an applied scenario, those who do have expertise will be quick to point out flaws in the scenario, which will detract from their engagement and willingness to take the scenario seriously. For a Detail-Oriented scenario, the active participation and engagement of students is critical. A Big-Picture focus, on the other hand, requires authenticity over accuracy. Students will understand that some simplification is necessary for a big-picture or strategic scenario, but if the scenario does not seem realistic it will detract from their ability to experience plausibility illusion and ability to remain engaged with the scenario. With the focus shifting to more critical and strategic thinking, students should also have the opportunity to engage in the design or construction of the scenario to help them further think through the ramifications of different options and decisions.

Interconnectivity: Individual-User (I) vs Multi-User (M)

This category refers to a how many people simultaneously interact with the same environment. As the name implies, Individual-User systems involve a single user working within a given scenario and cannot see or interact with other students. Any other characters they may encounter or interact with are Non-Player Characters (NPCs) controlled by the system. In a Multi-User environment, students are operating within a common environment, and thus need to be networked together.

Individual-User systems can be useful for keeping a student in a controlled environment where the focus is on their own training and they cannot be distracted by other students. It also allows them to make mistakes and rapidly repeat scenarios without disrupting any other students. However, they do not allow the concurrent execution of tasks and decisions that are interdependent, which can limit their applicability for more complex team environments. It also makes it more difficult to produce a realistic experience if the user needs to interact with Non-Player Characters (NPCs), and there is no ability to have a team practice together. This means that particular attention needs to be made in designing NPCs and the overall way the system is engaging to the user, as there is no external pressure to engage coming from other participants. In a Multi-User environment, there are both technical and curricula considerations to address when implementing VR/AR systems. On the technical side, a Multi-User environment will require network infrastructure to link the students into a common environment, and the infrastructure requirements will vary dramatically depending on the scale and intent of the environment. For example, if users need to access the environment from different locations, a central server environment must have enough processing power, network bandwidth, and other technical enhancements to support the use case. One the curricula side, the way the environment allows students to interact must be carefully considered, as the environment should be designed to prevent students who are either struggling or being intentionally disruptive from negatively impacting other students.

Table 1. Summary of Key Design Considerations

Design Consideration	**Subject-Focused (S)**	**Learner-Focused (L)**
Consistent content delivery vs interactive/adaptable environment	Consistency	Interactive
Engage by requiring actions vs providing an engaging environment	Actions	Environment
	Skill Based (K)	**Application Based (A)**
Provide immediate vs detailed feedback	Immediate	Detailed
Repeatable vs Engaging Scenario	Repeatable	Engaging
Focus on the specific task vs scenario as a whole	Task	Scenario
	Detailed-Oriented (D)	**Big-Picture (B)**
Accuracy of specific details vs Authenticity of the scenario	Accuracy	Authenticity
Students only participate vs help construct/control the scenario	Participant	Construction
	Individual (I)	**Multi-User (M)**
Investment in End-user devices vs Network Infrastructure	End-user	Infrastructure
Boundaries on student behavior vs realistic player/NPC interaction	Realistic	Boundaries

Curriculum Types

Taking into consideration each possible combination of the different categories, there are sixteen potential outcomes, which are summarized in Figure 1. In terms of impact to a VR/AR system, there are four distinct types that drive distinct changes in the way the system emphasizes material: subject matter expertise, management skills, skill demonstration, and strategic thinking. For example, whether the system is an open-world format, where the student can choose whatever tasks they want to use, versus having a set progression, is a technical design difference, but not one that alters the educational goal or focus level of the curriculum.

KDs – Skill Development

The types of curriculum in this category provide training that is focused on developing core skills and fundamentals. In other words, the focus is on providing consistency of content, rather than consistent educational outcomes. Most classroom-based training falls into this category, where the lesson material is planned in advance and follows a set schedule to build concepts over the length of the course. This type's strength is in a focused, organized curriculum that provides consistency and repeatability, which is partly why it is a common method in schools that need to ensure every student receives the same education. The primary weakness of this design is it is difficult to adjust to the needs of an individual student, meaning some students may fall behind, find the material repetitive or boring, or simply not respond to the curriculum. Students will naturally diverge in their level of understanding and as a result, there will be a mixture of students who excel, pass, and fail the course.

A VR/AR system in this type of curriculum should prioritize student engagement, while using immersion and presence only to the extent that they enhance engagement without distracting from the instructional material. This means that hyper-immersive simulators are not recommended, and if head mounted displays are used, care should be taken to make sure the technology or the virtual environment keeps the user focused on the specific skills being covered. Since the material is focused on core skills, the ability to quickly repeat and practice is required to help students gain proficiency. This also means the plot and other engagement factors are critical in order to keep the students' attention given the repetition needed to practice required skills.

KBs – Critical Thinking

This curriculum type helps students develop more critical thinking skills in a specific subject area to provide more well-rounded capabilities. This type of training is typically used for mid-level employees or those who are entering management, who need to focus on how the specific skills they already know fit into a larger context. Similarly, this curriculum is also used to help teams understand how they can be best used within a larger scope of effort. A VR/AR system in this type of curriculum should follow the same principles as a system in a KD curriculum type, prioritizing engagement, with immersion and presence used only to enhance engagement without distracting from the instructional material. However, the difference is in the way the system engages with the student. Rather than place the student in a role where they are tasked with executing individual actions and are assessed based on their individual skill, in a KB environment the student needs to learn the skills required to coordinate different skills, people, and priorities as part of a larger effort. This could be something like a first-line supervisor learning to manage a small team, or an engineering student learning to combine different core skills to tackle a larger engineering challenge. A military example would be training people who are part of an operations center to understand how their specific career field fits into the larger context of a multi-unit operation.

The technical requirements of a VR/AR system will be similar to the KD environment, where hyper-immersive simulators like CAVE systems are not recommended, and if head mounted displays are used care should be taken to make sure the technology or the virtual environment keeps the user focused on the specific skills being covered. Where this type diverges from KD will be in the way the students engage with subject material. Rather than focusing on learning or performing specific details or tasks, students need to be focused on constructing the plans and approaches to the different scenarios, which also means the system needs to be responsive enough to adjust to the different choices a student could make.

AD – Skill Demonstration

This type of curriculum is where the overall goal shifts from teaching new skills to successfully applying them. Rather than providing problems with an obvious path to a solution, AD curricula set scenarios for the student to solve with the various tools they have. This design's strength is ensuring students can apply their skills in the real world, rather than just answer test questions on a preestablished topic. The downside is it is more complicated to design and implement a system that students can repeatedly use without becoming too repetitive or enabling the student to "cheat" by learning the scenario.

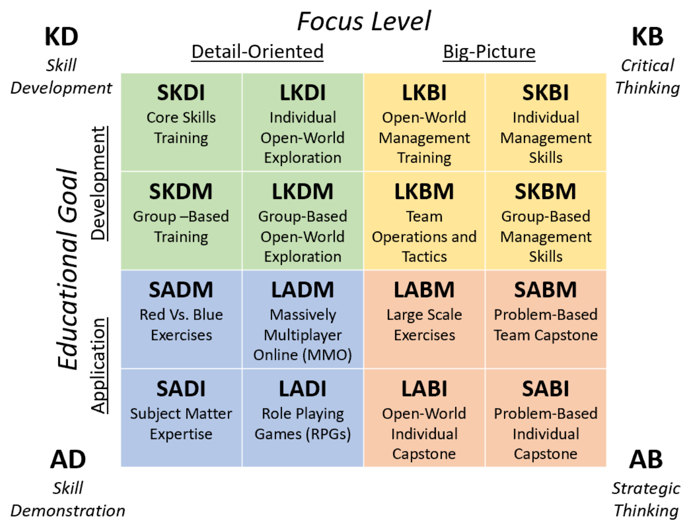
With the shift towards demonstrating skills instead of learning new ones, a VR/AR system in this type of curriculum should place more emphasis on immersion and presence to enhance engagement. This means that both Cave Automatic Virtual Environment (CAVE) systems and head-mounted displays are viable options, as the student needs to experience the place and plausibility illusion to be an active participant. This also means the plot and other engagement factors are critical in order to keep the students' attention.

AB – Strategic Thinking

This type of curriculum is where students need to not only think critically but think strategically. This is often applied in capstone or other scenarios where the objective is to assess whether the person understands how best to apply their skills and knowledge to solve a larger problem, and is generally the type of training that more seasoned leaders and managers would receive. What is most important is that students are able to apply a system-of-systems approach, understanding where different capabilities and people would be best utilized and what the consequences of those decisions would be. While large-scale military exercises would certainly fall within this category, it is by no means the only example. Being able to spot opportunities for process improvements, new ways of doing business, or when it is time to cancel a project are all objectives of this type.

Similar to AD curricula, a VR/AR system in the AB type of curriculum should put more emphasis on immersion than in the skill-based curriculum. However, with this type being focused on strategic thinking, presence and place illusion is not as important; for example, providing the student with a birds-eye view of a battle taking place in order to contextualize the effect of different unit movements undermines the place illusion but enhances the application's value and relevance to the student. Instead, plot and plausibility illusion are the most important aspect of the system design. In a big-picture scenario, students will be comfortable with some simplification of details for practicality, but if the scenario is not plausible, they will have a hard time staying focused or taking it seriously, fighting the scenario instead of meeting learning objectives.

Figure 1. Curriculum Outcomes Matrix



CONCLUSIONS AND FUTURE WORK

Summary and Recommendations

The excitement around the continued improvement of Virtual and Augmented Reality systems can lead to a confusing environment when trying to choose a system. Choices range from highly immersive simulators with incredible graphics to an app on a smart phone, and procurement professionals need to take a step back to examine exactly what the educational goals are for their specific use case. Research has shown that the ability to provide students with just the right amount of challenge, where the skill for a task is just beyond their current abilities yet attainable, is more impactful than other features of these systems. Beyond that, the myriad design features available in VR/AR systems have their time and place to be most beneficial. If the desire is to teach students to think critically and operate in a simulator that allows them freedom of movement to make choices and mistakes, an open-world VR format would excel. Whereas an initial tech school that needs to teach thousands of students a year needs a much more constrained and focused environment. Perhaps the best feature of VR/AR is this adaptability, where systems can be designed and molded to fit just about any use case with enough forethought and planning. VR/AR is a tool that can support and enhance any curriculum, but it must be designed to integrate with, not replace, the curriculum.

Research Contributions and Future Work

This research provides decision makers with a familiar personality-test style framework to help them determine what specific features and design considerations will make their VR/AR system most effective. There are several opportunities for future work. First, a questionnaire could be developed that would help decision makers determine the type of curriculum matches their educational goals, similar to a Meyers-Briggs exam, since those seeking to procure a VR/AR system are typically not professional educators. Secondly, additional research needs to be conducted to validate that this framework is useful and effective at assisting decision makers select VR/AR systems to meet their use case. Finally, research needs to be performed to evaluate the recommendations provided for each of the curriculum types.

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