Salient Features of an Effective Immersive Non-Collaborative Virtual Reality Learning Environment

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ABSTRACT
The use of immersive virtual reality learning environments (VRLEs) is changing the way students learn and understand things. A VRLE allows its users to get immersed in the simulation, thus giving the sense of being part of the real world that it represents. Virtual Reality (VR) existed in various forms in the past two decades, but its early adoption in education was hampered by its high cost. Emergence of affordable head-mounted displays (HMD) is now making it possible to provide VR experience in classrooms. This paper aims to apply integrative review of relevant studies conducted in evaluating the effectiveness of VRLEs and in doing so reveal the existing research gaps among VRLE studies. This paper identifies salient features of a fully immersive and non-collaborative VRLEs that uses HMD. Salient features were derived from evaluating different instruments used to measure the effectiveness of immersive VRLEs. A framework and example of instruments to evaluate salient features of an effective VR, using Kokoda VR as a case study, are also provided.

CCS Concepts
• **Applied Computing →Education →Interactive Learning Environments**

Keywords
Virtual Reality Learning Environment; Immersive Learning Environment, Technology in Education; Salient Features

1. INTRODUCTION
For many years, schools and universities had to change to way they teach in order to employ the latest technology to provide the best learning experience. From the use of software like PowerPoint, to the introduction of multimedia and online learning technologies. The introduction of new technologies being designed and used specifically for education is changing the way students learn and understand things. One such technology is virtual reality (VR).

VR has existed in various forms in the past two decades, but high cost became a main barrier for its early adoption in education, outside of experimental studies [11]. The emergence of affordable head-mounted displays (HMDs) is now making it possible to provide immersive virtual reality experience in classrooms. Virtual reality learning environments (VRLEs) is an application of VR in education which allow its users to get immersed in the simulation, thus giving the sense of being part of the real world that it represents.

Immersive VR is considered the next frontier for education. It is a powerful platform that gives students the opportunity to interact with content in three-dimension thereby providing a personal and meaningful experience. Although immersive VR seems to offer promising educational benefits, there are still many issues that need further investigation. As with any new technology applied in education, it is important to note that this technology is merely a tool that need to be carefully and effectively designed and implemented [20]. Salient features need to be identified before designing and implementing such technology.

1.1 Case Study
In July 2017, Torrens University Australia and the Australian Broadcasting Corporation (ABC) collaborated to develop Kokoda VR, a fully interactive Virtual Reality experience that immerses students in the main events of the Kokoda Track campaign in WWII. Kokoda VR is a pilot for an innovative production methodology which incorporates the photogrammetry method of scanning real objects and locations to be used in the virtual world [1]. It also features original museum artefacts, historical interviews and videos. Unlike 360˚ video, a 3D reconstruction of a location using photogrammetry allows users in VR to walk around the scene, pick up and inspect objects. Soundscapes that respond to the user's location and self-guided actions further increase the immersion in the experience. Autonomous exploration of these real-world locations increases the agency of the user.

The Kokoda VR's purpose was for it to be used in classrooms for high school students and older; and be used as supplement when discussing Australian WWII history. However, there is still a need to study if Kokoda VR is an effective learning tool. Do learners construct meanings they engage with the virtual reality experience? There are issues that needs to be studied further on the effectiveness of using immersive, realistic and interactive virtual worlds as tools in education. To be able to evaluate the effectiveness of VRLEs like Kokoda VR, the first step is to identify salient features specific to the use of immersive VR in education.

This paper aims to evaluate relevant studies conducted in analyzing the effectiveness of VRLEs and by doing so reveal the existing research gap among VRLE studies. This paper proposes salient features of an effective immersive VRLEs such as those

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achievable through the use of HMDs and that are non-collaborative (or individualized learning experience). These salient features focus on VRLEs that are fully immersive and were derived from evaluating different measures used to assess the effectiveness of an immersive VRLEs.

The next section presents the approach used to review these studies and identify the salient features. It will then be followed by the presentation of the results. Examples of instruments in assessing these features using Kokoda VR as case study are also provided.

2. APPROACH

In the current analysis of studies in evaluating effective VRLEs, we use the integrative review approach that involve summarizing the data achieved by collating data [39] .

2.1 Data Source and Search Strategies

The following strategies were employed to identify studies to include in the review:

1. Electronic searches were performed using the Web of Science, one of the highly recognized databases indexing essential journals, to search for research articles.
2. Keyword search terms include, virtual reality, immersive learning environment, virtual learning environment.
3. The next step was to refine it to search words such as education, learning, and evaluation.

2.2 Inclusion and Exclusion Criteria

Studies were either included or excluded based on the following criteria:

1. The time span was from 2013-2018 to focus on the current status of VRLEs and the period when high quality HMDs became more accessible.
2. Studies that focus on just the use of virtual reality (not augmented reality and mixed-reality, or combination of these technologies).
3. Studies that used non-collaborative use of virtual reality.
4. Studies that measured the effectiveness of the VRLEs.
5. Studies that used head mounted displays (HMDs).
6. Studies that were developed specifically for learners with disabilities were excluded from the study.

2.3 Analysis

The articles were analyzed using an integrative review method [42] which includes data reduction, comparison and interpretation. In data reduction, the data in each article was categorized in a matrix according to the type of VRLE, objectives, evaluation methods, and features measured (see example in Table 1).

Table 1: Example data reduction.

Reference	Applica-tion	Objective	Evaluation Method	Salient Feature
Bharathi et al. [6]	HMDs used in interactive VLE for online engineering design activities	Test if immersive VRLE improve task performance	Task-based performance evaluation (completion)	Performance

The next step was to make comparison across the different studies guided by the aim of the research. Salient features were identified by finding patterns and clustering features by their relatedness to each other. Lastly, the results of the review were synthesized and interpreted in relation to different studies.

3. RESULTS

3.1 Study Sample

An initial search returned 13,453 hits that match the keywords and time span criteria. After refining the search using the words education, learning and evaluation, 169 articles were considered for full review. Descriptive analysis was used on the studies included and the first author used the inclusion and exclusion criteria as the guide. Another author was asked to independently asses for confirmation. The reviewers disagreed on 2 studies, yielding a 92.3% agreement and a Kappa coefficient of 0.98. The two papers were discussed, and a consensus was reached. Articles excluded either involves collaborative environment (n=19); specific for people with disabilities (n=10); used mixed-reality(n=24); or used non-HMD VR, such as desktop or projected screen (CAVE) (n=92). A total of 24 studies qualified to be included in the study.

The 24 articles reported findings from different applications of VR in education but mostly in science and engineering activities (n=8, followed by safety training (n=4); experiential (place and nature) (n=4); space education (n=3); medical(n=2); music (n=1); narrative stories (n=1); and construction education (n=1).

Comparing the features measured in the studies, features that exemplifies the same thing or goal is coded in the same name and identified as a salient feature. For example, understanding of concepts and test learning of the concepts were all coded under mastery learning. There were 12 salient features identified in the sample studies. These are: presence, mastery learning, perception, immersion, performance, engagement, embodiment, usability, knowledge retention, empathy, motivation, elicit emotion. Empathy and elicit emotion were not coded as the same feature because the intent used in VRLE evaluations were different. Eliciting emotion focuses on the user's emotional state (e.g., joy, anger and anxiety) while the goal of empathy is to measure the user's ability to understand someone's emotion. The same with mastery learning and knowledge retention. They were coded into separate features because mastery learning measures student's mastery on unit tests before moving on to next [8], while knowledge retention is defined as the quantity of knowledge retained by an individual after a specific interval of time [13].

Scrutinizing the features measured by the samples revealed that presence is the most measured feature in the studies having 37.5% (9/24). Figure 1 shows the details of the proportion of the features. It also revealed that majority of the samples (54.2%; 13/24) carried out multi-feature evaluations of VRLEs.

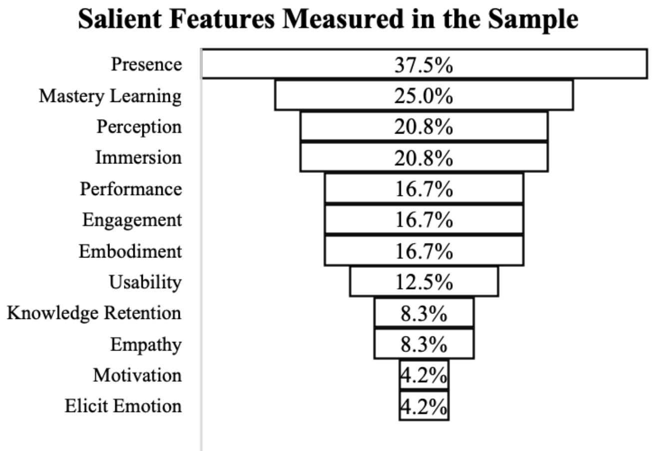

Figure 1: Proportion of the features measured in the sample.

Assessing the publication year of the samples, it shows that there is a significant increase of evaluations of VRLEs using head-mounted displays in the past two years (2017-2018). This can be attributed to the increasing affordability and availability of VR devices.

3.2 Salient Features of Immersive and Non-collaborative VRLEs

The 12 salient features identified for immersive and non-collaborative VRLEs are presence, immersion, perception, mastery learning, knowledge retention, performance, motivation, engagement, usability, embodiment, empathy, and elicit experience.

These salient features were categorized into three classifications: technical, human factors and learning. Table 2 shows the classification of salient features. The technical classification includes features that are mainly triggered by the VR technology being used (e.g., VR devices); human factors include features that are influenced by understanding psychosocial factors such as how humans perceive, engage and are affected by stimuli; and learning include features that are used to measure the students learning.

Table 2: Classification of Salient Features

	Technical	Learning	Human Factors
SALIENT FEATURES	Usability	Knowledge Retention	Presence
	Immersion	Mastery Learning	Perception
	Embodiment	Motivation	Engagement
		Performance	Elicit Emotion
			Empathy

Recent studies have shown that the VR industry‘s development focus in the next coming years is in perception, interaction and content creation [16]. Bamodu & Ye [5] has the same view stating that the quality of any VR is determined by focusing on features such as interaction and perception but adding immersion as another important feature.

3.2.1 Presence, Immersion and Perception

The most measured feature is presence having 37.5% (9/24) of the sample using it (e.g., [9,15,21,22,23, 27,28 34,35]). Effectiveness of virtual environments is often linked to the sense of presence. Presence is important in virtual world learning where it represents how close the interactions and presentations mimic the real-world experiences [40].

The most common features that were measured together were presence and immersion, even with immersion measured by only 20.8% (5/24) of the samples [22,24,28,34,35]. Samples that measured immersion also measured presence.

Immersion and presence are two interrelated but different features of VR that are often used to evaluate effectiveness of VRs. Immersion is a “technology-oriented” aspect of VR that gives the brain the impression that we’re in another place through visual information, audio or haptic feedback. The more that a system delivers displays in all sensory modalities, the more it is “immersive” [26]. Presence is the psychological, perceptual and cognitive consequence of immersion [36]. Slater et al. [36] has distinguished immersion from presence, with the former indicating a physical characteristic of the medium itself for the different senses involved. The sense of presence is indeed the subjective sense of being in the virtual environment. It is said to be the human reaction to immersion. It is the psychological perception of "being in" or "existing in" the VE in which one is immersed. Sense of presence seems to be related to immersion and several studies have shown that immersive capabilities of technology, specifically VR technology, impact the subjective feeling of presence [36].

All samples that measured presence and immersion used self-reported questionnaires as their evaluation method. Some samples included physiological measures such as the use of electro-dermal activity (EDA) [27,35]; blood volume pulse (BVP) [27]; and simulator sickness questionnaire[28]. Shin et al. [35] and Shin [34] included in their evaluation methods focus groups and interviews. Dang et al. [22] used immersive tendencies and presence questionnaires to measure subjective presence using different methods and one of them is VR observation in clinical training. The use of VR here is for purely observation and does not allow students to interact and pick-up objects. This study acknowledged that learning performance should have also been measured.

Considering that all samples used HMDs, the number of samples that measured immersion is small. Either the studies assume that immersion is there by default because of the technology used or it was removed out of the study and focus was on the VRLE. The incompleteness of the evaluation is already seen in these cases.

Presence and perception are also interrelated. Our perception is what we base our decisions on and mostly determines our sense of presence in the environment [19]. Perception in VR is the term used to describe how we take information from the virtual world and build understanding from it. Perception in this study was measured by 20.8% of the sample [29, 30,32, 33,35]. Perception is often measured by asking students if they think that using VRLEs is better compared their traditional way of learning, such as classroom or laboratory [32]. Despite the relationship between presence and perception, only Shin et al. [35] have evaluated these features together.

3.2.2 Mastery Learning, Retention, Performance and Motivation

Some VRLEs focused on measuring its effectiveness through students learning. There are four different aspects of learning that were measured: mastery learning, knowledge retention, performance (or task-based learning) and motivation.

Mastery learning, which was introduced by Bloom [8], maintains that students must achieve a level of mastery (e.g., 90% score on a test) in pre-requisite knowledge before moving forward to learn subsequent information. Mastery learning is the second highest feature (25%; 6/24) that were measured by the samples [7,13,16,24,29,30]. Most of the samples used pre and post-tests to measure learning [7,18,24,29,30] while Butt et al. [14] wanted to identify if using VR promotes mastery learning and asked participants to answer two questions regarding the topic of study. Instead of measuring exact learning, Kuronen-Stewart et al [29] focused on the overall experience using quantitative questionnaires to measure perceived effectiveness in learning and similarity to real-life setting.

Knowledge retention is defined as the quantity of knowledge retained by an individual after a specific interval of time [12]. Only two of the samples measured knowledge retention (8.3%). Butt et al.[14] tested both the mastery learning and knowledge retention by conducting test two weeks after the students participated in the study. Butussi and Chittaro [16] tested for knowledge retention before, immediately after and one week after the study.

Performance was measured in some samples using task-based activities. Task-based approach assumes learning revolves around the completion of meaningful tasks. Bharathi & Tucker [6] used the time in completing task in measuring performance. Pirker et al [32] used questionnaires and recorded quotes from students when performing the tasks while Bhargava et al. [7] used post-cognition questionnaires.

Motivation directs behavior toward particular goals and increases initiation of and persistence in activities [31]. This feature is closely related to task-based activities. However, only Pirker et al [32] measured both performance and motivation.

3.2.3 Engagement

Engagement in VRLEs is a feature that is often measured with learning and training effectiveness. But before any learning can occur, users must be sufficiently engaged. Prior researches show that engagement influences learning [2,25,44]. 16.7% (n=4) of the studies measured engagement [2,15,16,32]. Pirker et al. [32] used questionnaires and quotes while conducting the study to measure both engagement and performance. Buttussi et al.[16] used questionnaires to identify engagement and learning. Their findings include that emotional arousal is beneficial in the retention of learned concepts, retention of knowledge was higher for those who use immersive VR and that immersive VR induced higher emotional response.

3.2.4 Empathy, Embodiment, and Elicit Emotion

Empathy can occur when a VR user is immersed in the virtual world. A recent study by Shin et al. [35] has suggested that empathy and immersion must be measured together. The reasoning relates to the notion that empathy can only be fully experienced when a user is adequately immersed in VR. For VRLEs that include narratives or story telling or experiential application, empathy and embodiment are being included in measuring the effectiveness of VRLEs. 16.7% (n=4) of the studies measured embodiment [3, 34, 35, 37]. Phenomological proposal argues that empathy depends on embodiment [45]. Embodiment is the only feature tested by Ahn et al. [3] and Stiefs [37] while Shin et al.[35] and Shin [34] measured both embodiment and empathy along with other features. Ahn et al.[3] focused on measuring embodiment, experienced by users via spatial presence and body transfer, through questions with 5-point interval scales; Stiefs [37] tested embodiment using questionnaires; while Shin et al.[35] and Shin [34] used interviews, focus groups and questionnaires to measure empathy and embodiment. Shin [34] argues that empathy and embodiment should be measured, he stated that the cognitive processes by which users experience presence, and flow of the narrative will determine how they will empathize with and embody the story.

Felnhofer et al., [23] is the only study that used “elicit emotion” along with presence as a feature to evaluate their VRLE. Emotional experiences in turn are related to presence, another important concept in VR, which describes the user’s sense of being in a VR environment. Specific application areas of VRLEs where eliciting emotion are useful are in experiential applications or narratives. In this study, 75% (n=3) of the samples measured presence but did not evaluate if they elicit emotion to its users.

3.2.5 Usability

Other studies on evaluating the effectiveness of VRLEs focus on usability and user satisfaction in general [13, 19, 35, 32, 38, 41]. Gil-Gómez et al. [25]. Priker et al[32] and Vergara et al.[41] created their own usability questionnaires while Butt et al. [14] used the System Usability Scale (SUS) which is a well established usability tool developed by Brooke [12]. Usability contributes to the overall user experience.

A closer look at the above-mentioned studies shows that the VRLE’s features evaluated varies from study to study. In this case, the omission in measuring some of the VRLEs salient features to evaluate its effectiveness is confirmed given the limited number of features measured by the studies. It is not clear whether features evaluated can be reliably and systematically prescribed given the wide range of goals of VRLEs. However, it is possible to classify those features that have been measured in evaluating VRLEs to reveal common and distinctive features among them.

4. APPLICATION TO KOKODA VR

The salient features identified in this study were used in developing the instruments for evaluating the effectiveness of Kokoda VR. All features under the technical and human factors classification were used but only knowledge retention and mastery learning were used under the learning classification. Kokoda VR presents history and is a linear narrative application which does not assess students based on the task they perform rather on their understanding of the content.

Examples of questionnaires applying salient features in surveys or focus group:

Presence: *I am not aware of my real environment.*

Engagement: *I was excited to explore new things.*

Perception: *What are the best aspects of using Kokoda VR/ / Kokoda 360° Video?*

Elicit Emotion: *I felt sad when I saw the soldiers got sick.*

Empathy: *I understand why the Australian soldiers were feeling that way during the ceremony at the Kokoda village.*

Usability: *I find it easy to navigate the surroundings using the VR device.*

Immersion: *I felt stimulated by the virtual environment.*

Embodiment: *I felt in control when I picked up the objects in the virtual world.*

Mastery Learning or Retention Question: *Why were the men in the 39th battalion poorly prepared for war?*

In the development of the questionnaires, standards for developing questionnaires for educational research and handbook of questionnaire development were also used as a guide [4, 10, 43].

5. CONCLUSION

This paper attempts to identify salient features of an effective immersive non-collaborative VRLE. The review reveals interrelated features and their classifications that can be used as a guide in designing and evaluating this type of VRLE. The interrelatedness of these salient features discussed in the results show the importance of using them together to have a complete evaluation.

Presence is the most measured salient feature among the samples but is often measured with immersion. Presence is the psychological, perceptual and cognitive consequence of immersion. Perception's relationship with presence is that our perception is what we base our decisions on and mostly determines our sense of presence in the environment. Immersion, embodiment and empathy are also connected. Those studies that measured together these features argued that immersion has an impact on empathy and embodiment; and supported by studies that empathy depends on embodiment [45]. These two features are considered important especially for experiential and narrative story types of VRLE application.

This paper also showed that although the samples are evaluating VRLEs, not all samples measured learning. Effective VRLEs should ensure that there is some form of learning (understanding of the concept, knowledge retention, performance). Depending on what is the goal of the learning, VRLEs should measure a combination of the features identified. Motivation is often associated with any form of learning but in the samples, motivation is measured with performance. Engagement is a salient feature identified in this study that was associated with learning. As discussed in the results, users must be sufficiently engaged before any learning can occur but only few of the samples measured these features together.

Usability is also an important salient feature that must be measured to assess the quality of the student's experience using VRLE.

According to Whittemore et al [42], one implication of a review is to guide practice. The salient features identified in this review was the basis for the development of the instruments for evaluating the Kokoda VR case study. We anticipate that this instrument will provide us with detailed knowledge of the effectiveness of Kokoda VR, which will form the basis for designing immersive and non-collaborative VRLEs. The application of the classifications of the salient features can also be used in evaluating other types of VRLEs depending on focus areas of evaluation. For example, using a new VR technology using an existing VR application would most likely focus on the technology features while using the same immersive technology would look at focusing on learning or human factors' features. VR designers can also use these results to improve the learning effectiveness and human factors' features of their design.

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