# Effectiveness of Virtual Reality on Learning Engagement:
## A Meta-Analysis

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## ABSTRACT

With its immersive, interactive, and creative capabilities, virtual reality (VR) has been widely used in educational settings to provide students with challenging real-world experiences. As a result, interest in its effectiveness has grown. The goal of this meta-analysis is to examine how VR technology affects students' motivation to study. A comprehensive analysis of the literature up to December 2022 revealed 15 randomized controlled trials or quasi-experimental studies. These studies were also coded to examine the moderating effects of their features, such as types of learner engagement, learner stages, learning domains, types of VR technology, and the moderating effect of knowledge types. The results indicate a large effect of VR on student engagement in learning (g=0.85). Furthermore, the findings of the moderator analysis demonstrate that VR has a more significant impact on cognitive engagement, higher education learners, immersive VR experiences, the field of art education, and procedural knowledge learning.

## KEYWORDS

Education, Information Technology, Learning Engagement, Meta-Analysis, Virtual Reality

## INTRODUCTION

Virtual reality (VR) is a technology that offers students the opportunity to engage with a computer-generated environment, allowing them to tackle complex problems directly (Burdea & Coiffet, 2003). Immersion, interaction, and imagination are the key features of VR that enable students to experience real-world scenarios, enhance their learning motivation, and yield positive learning outcomes (Radianti et al., 2020). VR allows for specialized skill training, such as flying an aircraft or operating a vehicle, as well as the observation of microscopic or macroscopic events, such as examining biological tissues. In recent years, the increasing power of computer processing, improved network transmission rates, and decreasing costs of VR equipment have facilitated the widespread adoption of VR in education and teaching. Consequently, the effectiveness of VR implementation is gaining significant attention (Brown et al., 2020).

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A century ago, Dewey (1916) proposed that students should "learn by doing," i.e., gain experience in real learning environments and learn by doing real tasks. As a result, a large body of research has concluded that virtual reality provides rich stimuli, facilitates natural interactions and experiences, and improves student engagement in learning due to the three-dimensional perspective and immersive space that it provides. Despite the generally positive attitude of researchers toward virtual reality technology, the available research has focused more on the impact of virtual reality technology on learners' academic achievement and lacks research on the impact on learners' academic experience. Lähtevänoja et al. (2022) suggested that the impact on indirect learning outcomes (e.g., motivation and engagement in learning) should be added to future research.

The purpose of this study was to explore the impact of virtual reality technology on learners' engagement, rather than focusing on the impact on their academic achievement. In addition, a moderated analysis was conducted to explore inconsistent results. Therefore, the research questions were as follows:

1. How effective is VR technology on the overall learning engagement of learners compared to non-VR technology?
2. How effective is the impact of VR technology on various aspects of learners' cognitive engagement, emotional engagement, behavioral engagement, and social engagement?
3. What are the moderating effects of the qualities that have been studied, such as the type of immersion in VR technology, the stage of learners, etc.?

## LITERATURE REVIEW

### VR Technology Types and Characteristics

VR technology is an emerging technology that integrates several disciplines such as computer graphics technology, human-machine interface technology, sensing technology, simulation technology, and artificial intelligence (Yang et al., 2010). It enables human-computer interaction and access to multimodal information through devices that immerse the user in a 3D virtual environment to achieve physical and mental interaction and a realistic perceptual experience. According to the level of immersion, virtual reality technologies are divided into two categories: non-immersive VR and immersive VR. Non-immersive VR technology, also known as desktop computer virtual reality, generally means that users can interact with the virtual environment through a mouse, keyboard, game console, or touchscreen (Cabero Almenara & Fernández Robles, 2018). Immersive VR can be categorized into two main types: semi-immersive VR and fully immersive VR. Semi-immersive VR technology refers to systems that allow partial sensory immersion of the user in the digital environment. To achieve this, the relevant sensory inputs are enhanced or the way the user interacts with the virtual environment is improved, as in the case of Google Glass (Di Natale et al., 2020). Fully immersive virtual reality technologies enclose the user's visual, auditory, and other senses and provide input devices such as 3D mice, data gloves, spatial position trackers, and visual-auditory and other devices to fully immerse the user in a new virtual sensory space. This technology can be divided into two types: head-mounted display devices and cave automatic virtual environment (CAVE) (Passig et al., 2016; Meyer et al., 2019). Head-mounted display devices are where the user wears glasses consisting of two LCD screens through which the system monitors the orientation of the user's head and, in some cases, the user's position. CAVE is a projection-based virtual reality technology in which the user is isolated from the external physical environment and the audiovisual perception is fully integrated with the virtual environment and a highly immersive experience is obtained in the CAVE environment (Muhanna, 2015).

## Learning Engagement With VR Technology

Learning engagement is considered to be the behavioral, cognitive, and emotional state in which students are actively engaged in learning (Schaufeli et al., 2002). Some studies have found that learner engagement in learning is positively related to learner academic achievement, the experience of attending school, lower dropout rates, increased learner satisfaction with school, and learners' future levels of career development and critical thinking skills (Howell, 2009). It has also been found that engagement in learning is malleable and that factors such as teachers' teaching methods and school management levels can have an impact on engagement in learning. According to Fredricks et al. (2004), learning engagement is a composite concept consisting of behavioral, emotional, and cognitive dimensions, including behavioral engagement, emotional engagement, and cognitive engagement. Behavioral engagement focuses on students' actions and the extent to which they participate in academic, social, and off-campus educational activities; emotional engagement reflects the extent to which students identify emotionally with teachers, peers, courses, and their institutions; and cognitive engagement considers students' intellectual investment in complex ideas and skills and their willingness to do so. Social engagement refers to the extent to which students feel connected to their peers and the broader university community (Bowden et al., 2017).

Because VR technology has three main characteristics–immersion, interaction, and imagination–it enables students to be immersed in a variety of environments and time periods when using VR technology in teaching and learning, breaking the limits of time and space and gaining experiential learning. Studies have been conducted to show that VR technology has a significant impact on students' learning engagement. Sun et al. (2021) found that students' interest and enthusiasm for learning can be fully developed through being in a VR technology-based learning situation, while there is a significant change in students' learning engagement and a significant increase in students' academic performance, problem-solving skills, and critical thinking skills. According to Hui et al. (2022), in a comparison between teaching in VR and traditional teaching in elementary school art classes, it was found that students were more likely to enter the mind-flow experience and have higher levels of learning engagement in the VR environment.

However, some studies have also found that VR technology does not significantly impact students' engagement in learning. Akman et al. (2023) used an educational virtual game called "Keşfet Kurtul" in teaching fractions in the fourth grade of elementary school and showed that while the educational virtual game helped to improve students' performance in mathematics, it did not have a significant impact on students' engagement in mathematics. Makransky et al. (2019) used 52 college students as subjects and found that although students' self-ratings were higher in the VR condition, the cognitive load was measured by EGG and found that students' cognitive load was also higher in the VR condition and there was learning overload leading to distraction.

Based on these studies, it is difficult to accurately determine the effect of VR technology on learning engagement. With the rapid development of technology, the types of technology becoming diverse, and the popularity of VR technology in teaching, it is necessary to increase research on the effectiveness of VR technology in teaching environments. In addition, most of the existing studies are about the effects of VR technology on students' academic achievement, learning outcomes, or learning performance, ignoring the effects on learning engagement (Di Natale et al., 2020; Wu et al., 2020; Yu, 2021; Coban et al., 2022; Villena-Taranilla et al.,2022). In this study, the existing empirical studies will be synthesized to explore the impact of VR technology on learning engagement.

In this meta-analysis, we integrated existing studies that examined the association between virtual reality instruction and learning engagement. To perform the meta-analysis, we followed the methodological approach proposed by Glass et al. (1981). This approach entails several steps for the meta-analyst, including (a) collecting relevant studies, (b) coding the characteristics of the included studies, (c) calculating effect sizes for each study's outcome measure using a standardized metric, and (d) exploring potential moderating effects of the study's characteristics on the outcome measure.

By adhering to this systematic procedure, we aimed to comprehensively analyze the relationship between virtual reality instruction and learning engagement.

## METHOD

### Data Sources and Search Strategy

For the literature search, we employed the search formula ("VR" OR "virtual reality") AND ("learning engagement" OR "study engagement" OR "student engagement" OR "learners' engagement") across multiple databases, including the WOS core set, Wiley, Taylor & Francis, Elsevier ScienceDirect, and other relevant databases. This search strategy aimed to retrieve relevant literature on virtual reality and its relationship to learning engagement.

Additionally, we conducted a second round of search using a "snowball" approach, wherein we examined the references of the literature obtained in the initial search. This snowball search method allows for identifying additional pertinent studies that might not have been captured in the original search, thereby ensuring a more comprehensive coverage of the relevant literature.

### Inclusion and Exclusion Criteria

The inclusion criteria for the meta-analysis were as follows: (1) articles published before December 2022; (2) studies involving K-12 or higher education learners; (3) randomized controlled trials or quasi-experimental designs; (4) studies that compared VR and non-VR conditions; (5) the dependent variable being learner learning engagement; (6) peer-reviewed journal articles; and (7) papers written in English.

Conversely, the following criteria were employed to exclude studies from the meta-analysis: (1) studies focusing solely on rehabilitation; (2) studies with a single-group design without a comparative condition; (3) studies where VR was used in both the experimental and control groups; (4) studies where the dependent variable consisted solely of self-reported data; and (5) studies that did not provide sufficient data for calculating effect sizes.

By applying these inclusion and exclusion criteria, we aimed to ensure that the selected studies met specific standards and were relevant to the research question addressed in the meta-analysis.

### Study Sample

After removing duplicate studies, 1,033 articles were obtained through databases and other sources. By browsing through the titles and abstracts and excluding irrelevant literature, a total of 187 articles were included in the study for further consideration; 172 articles were excluded for the following reasons (Figure 1):

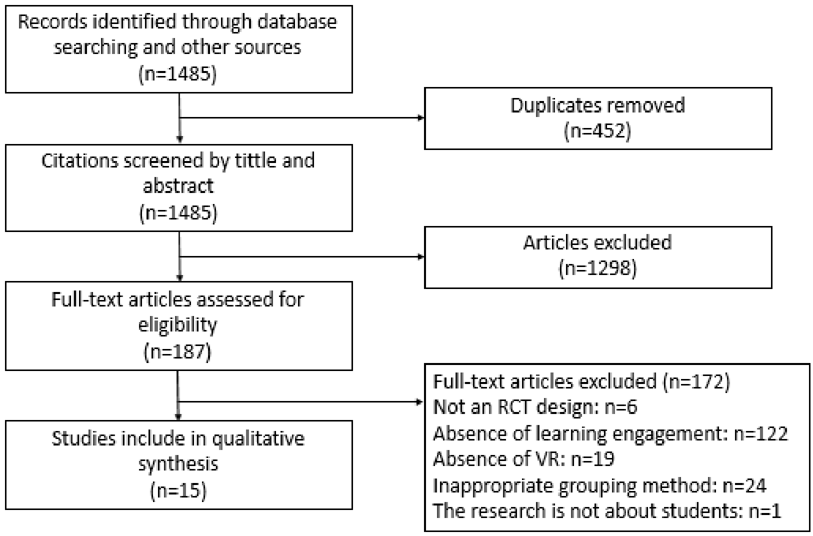
(1) 122 articles were excluded because they did not measure learning engagement;
(2) 19 articles were excluded because VR technology was not used;
(3) 1 article was excluded because the study population was not students;
(4) 24 articles were excluded because the applicable study design was not used (e.g., lack of inferential data, literature review, etc.);
(5) 6 articles were excluded because VR technology was used in both the experimental and control groups.

A total of 15 articles finally met all inclusion and exclusion criteria.

### Data Coding

To address the research question, we encoded the following moderator variables. The educational stage of learners was categorized as primary school, secondary school, and higher education. The learning domains encompassed the natural sciences, social sciences and humanities, and arts.

**Figure 1. Flowchart of the study selection process**




Regarding the knowledge types, this study categorized them into two categories: "declarative" and "procedural." "Declarative" refers to teaching activities focused on imparting factual information, while "procedural" refers to teaching activities that require students to perform tasks.

For VR technology types, this study classified them as "immersive" and "non-immersive." "Immersive" VR technology includes head-mounted displays and projection-based VR systems that can block out real-world stimuli and replace them with virtual content. "Non-immersive" VR technology, on the other hand, enhances the individual's sensory environment, such as desktop-based VR technology on laptops or tablets.

Regarding learning engagement, this study encoded it into five categories: "overall engagement," "behavioral engagement," "emotional engagement," "cognitive engagement," and "social engagement."

## Statistical Analysis and Data Synthesis Methods

The meta-analysis comprised several key components, including calculating effect sizes, assessing heterogeneity, and performing moderator analysis. The software Stata 15.0 was utilized for the analysis.

Each independent study's effect size was estimated based on sample size, means, standard deviations, t-tests, F-tests, and p-values to compute the effect sizes. Given that this study aimed to measure the effect size for continuous variables, Hedges' g was used as the standardized metric. Outliers were examined to ensure that no effect size exceeded the average effect size by three standard deviations. All samples adhered to the three-sigma rule. The random effects model was employed to calculate the overall mean effect size, accounting for the variation in research designs. The classification of Cohen (1992) was applied, where effect sizes of 0.2, 0.5, and 0.8 were considered small, medium, and large, respectively.

A homogeneity analysis was conducted to explore variance in effect sizes across studies. As Borenstein et al. (2010) proposed, the Q-statistic was used to assess whether the studies shared a common effect size. Larger Q-statistic values indicated heterogeneous effect sizes, which indicated the need for moderator analysis. In such cases, the random effects model was used. Homogeneity was further evaluated using $I^2$, which quantified the proportion of variation attributable to true heterogeneity. The guideline of Higgins and Thompson (2002) categorized $I^2$ values below 0.25, between 0.25 and 0.50, and above 0.70 as low, medium, and high heterogeneity, respectively.

As significant heterogeneity was observed among the studies, a further grouping of individual effect sizes was conducted to explore potential moderators that accounted for the variability. Moderator analysis was performed using mixed effects analysis to elucidate systematic heterogeneity in the effect sizes.

## RESULTS

### Descriptive Results

Following the screening process, the authors identified a total of 15 valid studies that assessed the engagement of VR technology in student learning. Although the literature search did not restrict the starting time, the selected literature in this study was first published in 2017, and the largest number of literature sources was published in 2022, with a total of six studies. Regarding the characteristics of VR technology, three studies used non-immersive VR technology, while there were 12 studies that used immersive VR technology. This also indicates that the number of immersive VR technologies used in teaching and learning activities has been increasing significantly in recent years.

The analysis of participant characteristics revealed that five studies examined college students, seven focused on elementary school students, and two included middle school students. One study had a sample that consisted of both middle school and college students (Calvert & Abadia, 2020). These findings indicate that the majority of the existing research on the impact of VR on student engagement in learning has primarily concentrated on college and elementary school levels, while relatively less attention has been given to investigating the effects of VR on secondary school students' engagement in learning.

Regarding the subject areas in which VR technology was utilized, four studies were conducted in writing classes, two in science classes, two in medicine and art, one in history, one in mathematics, one in language, one in architecture, and one in electronics.

### The Overall Effect of VR on Learning Engagement

We calculated the effect values for each study and the overall effect size for these 15 studies. Figure 2 shows the effect sizes for each study and the overall effect sizes for the effect of VR technology on learning engagement through forest plots. In terms of independent effect sizes, the effect sizes ranged from 0.03 to 3.27, all of which were positive, and the overall affection of the 15 studies was 0.85 with a 95% CI=[0.53,1.16], $p<0.001$, which reached a statistically significant level. The results of this study indicate that VR technology has a significant positive impact on learning engagement. However, the value of $I^2$ was 85.2%, showing a high level of heterogeneity throughout the model, which needs to be explained by one or more moderators.

This study measured the specific impact of VR on learning engagement in four areas: cognitive engagement, emotional engagement, behavioral engagement, and social engagement. As shown in Table 1, in terms of cognitive engagement, the effect size of the impact of VR technology on students was 0.467 ($p<0.001$), which reached a statistically significant level, indicating that VR can significantly and positively contribute to students' cognitive engagement levels. In terms of emotional engagement, the effect size for the impact of VR technology on students was 0.248 ($p<0.05$), indicating that VR technology has a significant effect on learners' emotional engagement levels. In terms of behavioral engagement, the effect size for the impact of VR technology on students was 0.458 ($p<0.01$), which indicates a significant moderate effect of VR on students' behavioral engagement. In terms of social engagement, the effect size of VR technology's impact on learners was 0.316 ($p<0.01$), which indicates a significant moderate effect of VR on learners' social engagement. Taken together, VR technology had a significant positive effect on the development of learners' cognitive engagement, emotional engagement, behavioral engagement, and social engagement levels, and the effect was most prominent at the cognitive engagement level. The results suggest that the facilitative effects of VR on learning engagement are multifaceted and multilevel.

**Figure 2. Forest plot of the effect size of VR technology on learning engagement**

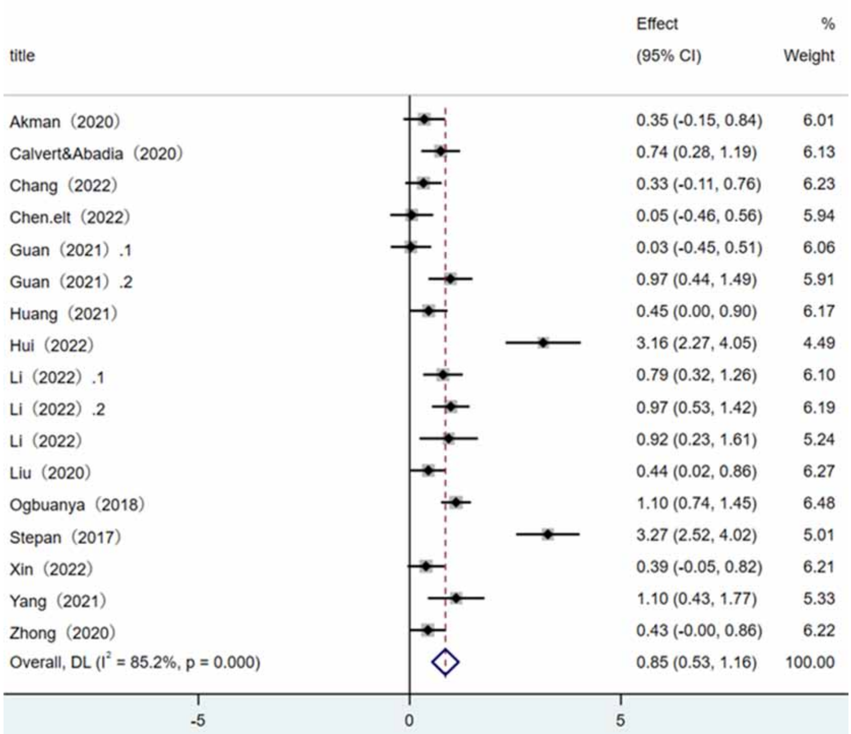



**Table 1. Analysis of the effect of VR technology on learning engagement**

| Dimension of Engagement | Number of Studies | Effect Size | 95%CI | | Z |
|---|---|---|---|---|---|
| | | | LowerCI | UpperCI | |
| Cognitive engagement | 8 | 0.464 | 0.296 | 0.631 | 5.430*** |
| Emotional engagement | 8 | 0.248 | 0.018 | 0.478 | 2.116* |
| Behavioral engagement | 8 | 0.458 | 0.177 | 0.739 | 3.192** |
| Social engagement | 7 | 0.318 | 0.260 | 0.482 | 2.655** |

## Moderator Analysis

### *VR Effect Size on Learning for Education Level*

The results of the moderating effects are shown in Table 2. In terms of different learning stages, current VR technology has been studied and applied at primary school, secondary school, and higher education, but mainly focused on primary school. The effects of VR technology on learning engagement, ranked by effect size, are as follows: higher education (SMD=1.158, $p<0.001$), primary school (SMD=0.832, $p<0.001$), mixed stage (SMD=0.735, $p<0.001$), and secondary school (SMD=0.466, $p<0.05$). These findings indicate that VR technology significantly enhances learning engagement at a moderate to high level across the elementary school, middle school, college, and mixed stages. The Q-statistics ($Q_B$=2.75, p=0.431) reveal no significant differences in the promotion of learning engagement across different educational levels. Specifically, the impact of VR technology on higher education students' learning engagement is the most significant, while the differences in impact between elementary and mixed stages are relatively small, and the impact on secondary school students is the weakest.

### *VR Effect Size on Learning for the Type of Technology*

To examine the differences in the effects of VR device types on learning engagement, this study classified VR device types into immersive VR devices and non-immersive VR devices. Q-statistics ($Q_B$=1.06, p=0.03) revealed significant differences in the facilitative effects of different types of VR technology on learning engagement. The effect size of immersive VR technology on learning engagement was 0.925 ($p<0.001$) and the effect size of non-immersive VR technology on learning engagement was 0.546 ($p<0.001$), indicating that the effect of immersive VR technology on learning engagement was better than that of non-immersive technology.

### *VR Effect Size on Learning in the Field of Education*

In order to examine the difference in the effect of VR technology on learning engagement in different subjects, this study divided the field of education into natural sciences, social sciences and humanities, and arts. Q-statistics ($Q_B$=0.89, p=0.64) revealed that there was no significant difference in the facilitation effect of VR technology on learning engagement in different fields of education. The best effect of VR technology on learning engagement was found in art with an effect size of 1.338 ($p<0.001$), while for both social sciences and humanities and natural science subjects, there was little difference in the effect of VR on learning engagement, with a moderate to positive effect.

### *VR Effect Size on Learning for the Type of Knowledge*

To examine the differential effects of VR technology on learning engagement in different knowledge types, this study categorized knowledge types into procedural knowledge and declarative knowledge, with VR technology primarily focused on teaching procedural knowledge. The Q-statistics ($Q_B$=2.85, p=0.041) reveal significant differences in the promotion of learning engagement by VR technology across different knowledge types. Specifically, in the context of procedural knowledge learning, the effect size of VR technology on learning engagement is 0.971 ($p<0.001$). In contrast, in the context of declarative knowledge learning, the effect size of VR technology on learning engagement is 0.515 ($p<0.001$). These findings indicate that compared to declarative knowledge learning, VR technology is more effective in enhancing learning engagement in procedural knowledge learning.

## DISCUSSION

### The Overall Effect Size of VR on Engagement

Based on the research findings, the overall effect size of VR on learning engagement is 0.85. This implies that VR-based instructional environments are more effective in promoting learning engagement than other technology-supported instructional environments. VR technology activates learners' visual and motor channels, providing them with a sense of immersion, leading to a deeper and more comprehensive understanding of the instructional content. This stimulation enhances learners' interest and motivation, resulting in greater engagement in learning activities (Huang et al., 2021; Li & Xue, 2023).

However, these findings are inconsistent with previous research where VR-based instructional environments did not significantly impact learning engagement compared to other instructional environments. This discrepancy may be attributed to the fact that individuals with learning goals might prefer acquiring knowledge through simple and direct means rather than being exposed to visually complex three-dimensional environments (Yu, 2021). We believe that the difference in effect size regarding the impact of virtual reality on learning engagement is primarily due to variations in sample size. Yu (2021) included only four research studies. However, in recent years, with the

**Table 2. Moderator analysis of learning engagement**

| Moderator | k | g | 95%CI | QB | p-Value |
|---|---|---|---|---|---|
| **learner stage** | | | | **2.36** | **0.5000** |
| Primary school | 8 | 0.832 | [0.382,1.282] | | |
| Secondary school | 3 | 0.466 | [-0.038,0.970] | | |
| Higher education | 5 | 1.158 | [0.366,1.949] | | |
| Mixed education | 1 | 0.735 | [0.276,1.195] | | |
| **VR technology** | | | | **1.06** | **0.03** |
| Immersive | 14 | 0.925 | [0.554,1.297] | | |
| Non-immersive | 3 | 0.546 | [-0.072,1.164] | | |
| **Learning field** | | | | **0.89** | **0.64** |
| Natural sciences, | 7 | 0.847 | [0.309,1.385] | | |
| Social sciences & humanities | 7 | 0.743 | [0.433,0.953] | | |
| Arts | 3 | 1.338 | [-0.155,2.831] | | |
| **Knowledge type** | | | | **2.85** | **0.041** |
| Procedural | 13 | 0.971 | [0.574,1.368] | | |
| Declarative | 4 | 0.515 | [0.166,0.864 ] | | |

widespread adoption and continuous improvement of VR technology, the number of research studies on VR-based instruction has been increasing. Consequently, the overall effect size is showing positive improvement (Coban et al., 2022).

## Effect Size of VR on Learning Engagement for the Type of Engagement

In the four types of engagement, we found that the effect size was highest between VR and cognitive engagement, followed by behavior engagement, with emotional engagement being the lowest. This finding is consistent with studies conducted by Guan et al. (2021) and Li et al. (2022), among others, which suggest that VR-based instructional environments are more conducive to the development of cognitive engagement. One possible reason is that VR display technology creates a visual and self-directed learning space for learners, allowing them to gain concrete experiences and reflective observations, which promotes cognitive reflection and engagement. Additionally, VR technology has a positive effect on behavior engagement. This is because VR, through its immersive and interactive properties, enables learners to manipulate specific objects in a virtual environment, stimulating their interest and motivation to maintain a high level of engagement. Moreover, guiding students to participate in collaborative discussions through VR-based instruction also contributes to their social engagement. Lastly, the impact of VR on emotional engagement is the smallest. This can be attributed to the fact that although VR technology helps create an immersive learning environment and enhances students' learning motivation, the transient nature of virtual reality experiences makes it challenging to have a significant impact on students' emotional factors. This finding aligns with the research conducted by Li et al. (2022).

## Effect Size of VR on Learning Engagement for the Education Level

Based on the research findings, VR has a significantly larger effect size in higher education compared to other education levels. This is because the novelty of VR technology can hinder users' learning experiences, especially if they have never used the technology before or are unfamiliar with it

(Hamilton et al., 2021). Unlike K-12 learners, college students can leverage their cognitive efforts to translate virtual images into real-world environments and connect them with instructional content. Additionally, college students are often goal-oriented and more focused on knowledge and skill acquisition. Therefore, in highly immersive learning environments provided by VR technology, learners are more actively engaged in the learning process.

Although the effect size of VR on learning engagement in K-12 education is smaller than in higher education, it does not mean that VR technology is unsuitable for K-12 students. For K-12 students, the learning process is often achieved through play and exploration. VR technology creates an ideal and practical learning environment for learners through multisensory stimulation. In this environment, learners can engage in experiential and inquiry-based learning through play, exploration, and object manipulation, embodying "learning by doing." This is why VR technology is more popular in K-12 education.

### Effect Size of VR on Learning Engagement for the Type of Technology

Based on the research findings, it was observed that VR has a larger effect size in non-immersive VR compared to immersive VR (Alhalabi, 2016). It has also been noted that participants in immersive VR systems are willing to invest more time in learning tasks. The impact of non-immersive VR and immersive VR on learning engagement may vary, and it is possible that this difference is due to the distinct characteristics of each technology.

Researchers generally agree that immersion is a crucial element in influencing psychological factors such as a higher sense of presence, increased engagement, positive attitudes towards learning subjects, and better learning perceptions (Wu et al., 2020). Immersive VR breaks the constraints of temporal and spatial sensory perceptions, providing a more realistic environment for learning. It goes beyond the traditional visual stimuli of non-immersive VR (e.g., 2D or DVR) and facilitates a higher degree of involvement.

Furthermore, immersive VR combines tactile interfaces (such as wearable sensors) with head-mounted displays, enhancing the level of interaction and control during the learning process. This integration is more conducive to knowledge transfer and task solving, as learners can actively engage with the virtual environment through physical actions and feedback. The combination of visual, auditory, and tactile stimuli in immersive VR creates a more immersive and realistic learning experience, leading to a larger effect on learning engagement.

### Effect Size of VR on Learning Engagement in the Field of Education

Based on the research findings, the effect size of VR was calculated at a very large level (g=1.338) in the art field and at a medium level (g=0.847, g=0.743) in the STEM and humanities fields. This indicates that VR technology is an effective tool in art education. Virtual reality technology can inspire learners and stimulate their imagination, creating an immersive creative environment that is conducive to fostering creativity. Additionally, the additional tools available in VR software can assist learners in creating works of art, inspiring creativity and enhancing the quality of their creations (Hui et al., 2022).

Furthermore, research suggests that the application of VR in the field of education often focuses on STEM subjects such as natural sciences, mathematics, and engineering. These disciplines often involve abstract concepts, and VR technology can help learners better understand the practical applications of these concepts. By providing immersive experiences and interactive simulations, VR technology facilitates a deeper comprehension of abstract ideas (Hamilton et al., 2021).

Lastly, contrary to previous research, this study found that VR has also been applied and shown significant effects in the humanities and social sciences fields, such as history and language. This is because VR technology can provide learners with highly immersive learning environments, generating a strong sense of engagement and allowing learners to actively and enthusiastically participate in the learning process.

### Effect Size of VR on Learning Engagement for the Type of Knowledge

Based on the research findings, VR technology is predominantly utilized in the learning of procedural knowledge, and it demonstrates superior effectiveness. This aligns with the findings of Hamilton et al. (2021) and other researchers. The rationale behind this lies in the creation of virtual learning environments through VR, enabling students to engage in learning activities related to high-risk subjects without posing any real-world risks to themselves or others. Moreover, VR allows for the transcendence of temporal and spatial limitations, facilitating repeated practice sessions. For example, it has been employed in scenarios such as handling operating room fires (Sankaranarayanan et al., 2018) and tying surgical knots (Yoganathan et al., 2018).

However, there are researchers who question the efficacy of VR technology, suggesting that it may simply generate a "getting good at the game" effect. For instance, Jensen and Konradsen (2018) assert that training procedural skills in VR might only enhance learners' proficiency within the virtual environment without necessarily transferring the acquired skills to the real world.

These points of skepticism prompt us to consider various factors when evaluating the effectiveness of VR technology in procedural knowledge learning, including skill transferability, task authenticity, and its impact on learner motivation and interest. Further research and practical exploration are required to better integrate VR technology with real-world application scenarios, ensuring the effective transfer and utilization of acquired knowledge and skills in practical contexts.

## CONCLUSION

The primary aim of this meta-analysis was to synthesize the findings from various studies and determine the impact of VR, in its different forms, on learning engagement. Based on the results obtained, the main conclusion of this study is that VR has a positive influence on learning engagement. Additionally, the analysis of moderator variables has yielded crucial insights for future research considerations.

First, among the three types of learning engagement, VR has the most significant effect on cognitive engagement. Furthermore, the study found that immersive VR is more effective than non-immersive VR in promoting learning engagement. Additionally, VR technology appears to have positive effects across various disciplinary domains and is particularly effective in teaching procedural knowledge. These findings could have important implications for educators and researchers who are interested in using VR technology to enhance learning outcomes.

However, this study has two limitations. First, some empirical studies lacked sufficient statistical information for calculating the effect size effectively. Consequently, these studies could not be included in the meta-analysis, potentially impacting the results. Second, most prior studies have treated learning engagement as one of the outcome measures without conducting in-depth analyses. This limitation restricts our ability to comprehensively examine the impact of VR technology on learning engagement.

In summary, research on the effects of VR on learning engagement is still in its nascent stages. This meta-analysis encourages further exploration of more effective approaches to enhance students' levels of learning engagement in the future.

## AUTHOR NOTE

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