Immersive Virtual Reality is More Effective Than Non-Immersive Devices for Developing Real-World Skills in People with Intellectual Disability

Abstract

People with intellectual disability demonstrate persistent challenges around developing life skills. Immersive virtual reality (IVR) is gaining interest as a tool for training life skills as it enables individuals to engage in hands-on learning in a safe, controlled, and repeatable environment. However, there are concerns about the potential drawbacks of IVR, such as cybersickness and practical challenges with using VR equipment, which may hinder its widespread adoption in educational settings. The current study aimed to compare the effectiveness of training in IVR and a non-immersive virtual environment for improving real-world skills in people with intellectual disability.. In the present study, 36 adults (16f, 20m) with intellectual disability were recruited from a disability organisation. Participants completed a real-world assessment of waste management skills before and after training in either the IVR or non-immersive group. Consistent with our hypotheses, the IVR group scored significantly higher in the real-world assessment after virtual training (d = 1), and at the one-week follow-up (d = 1.12), compared to the non-immersive group. Further analyses showed that the IVR group, but not the non-immersive group, significantly improved performance in the real-world assessment across timepoints. Our findings indicate that IVR was more effective for improving and retaining real-world waste management skills. This study supports IVR as a viable tool for professionals and caregivers to develop skills for independent living among people with intellectual disability.

Keywords: intellectual disability, immersive virtual reality, virtual environments, life skills, experiential learning.

Introduction

People with intellectual disability often require intensive support from caregivers to manage activities of daily living [1]. This reliance largely stems from challenges in intellectual and adaptive functioning [2]. Difficulties in adaptive functioning impact the ability to perform the social, conceptual and practical skills necessary for everyday life [3]. Over 60% of people with intellectual disability experience severe or profound challenges in performing life skills [4]. These are the practical skills required to complete everyday tasks without the need for caregiver assistance such as cooking, showering, and cleaning [5]. Difficulties in performing life skills prevent people with intellectual disability from living independently, which is associated with decreased feelings of happiness and poorer quality of life [6]. Therefore, there is a need to find effective methods for developing life skills in this population.

People with intellectual disability often face challenges in conceptual understanding and working memory, which can limit their ability to process and retain information that is not visually or externally represented [7]. Conversely, people with intellectual disability have unique characteristics that make them well-suited for experiential learning [8, 9]. *Experiential learning* (or ‘learning-by-doing’) describes the cyclical process of gaining knowledge through direct and hands-on experience of a task and then applying this knowledge to future problems to consolidate motor learning [10]. Methods that utilise hands-on interactions have largely found to be effective [7, 9, 11]. Research shows that experiential learning is more effective for developing skills among individuals with ID compared to passive and didactic methods of learning [12, 13]. For example, Scruggs, Mastropieri [13] compared two groups of high school students with intellectual disability who learned science-based skills from either a practical lab-based activity or reading a textbook. They found that the practical activity group performed significantly better than the textbook group in a post-test skill examination. Therefore, there is promising but limited research demonstrating the benefits of experiential learning for improving skills among individuals with intellectual disability.

Opportunities for people with intellectual disability to participate in hands-on learning are often minimal due to concerns surrounding risk of injury, time restraints, and lack of staff training [14, 15]. Disability support workers report that minimal time, resources, and professional training limit their ability to provide opportunities for in-vivo experiences for their clients [15]. While perhaps optimal for skill development, experiential learning also introduces potential hazards. Certain activities may lead to injuries such as mastering the safe crossing of bustling streets or handling household waste that contains items such as broken glass. This risk is particularly pronounced for people with intellectual disability, who are more likely to incur preventable injuries in comparison to people without disability [16]. In response to these challenges, immersive virtual environments emerge as a strategic solution, offering controlled, hands-on, and realistic learning experiences in a safe and controlled environment [17, 18].

Immersive virtual reality (IVR) is a simulated digital environment that replicates aspects of the real world or imagines entirely new worlds, designed to completely immerse users' senses and create the sensation of being physically present in that environment [19]. This immersive experience is typically facilitated by technologies such as head-mounted displays (HMD) [19]. One of the pivotal advantages of IVR is its capacity to enable the training of realistic gestures and movements within a safe and repeatable setting. This unique attribute establishes HMDs as an ideal instrument for experiential learning, where participants can navigate and interact with lifelike scenarios without real-world risks [20, 21]. However, despite its promising application, there is a discernible gap in research exploring its efficacy in enhancing life skills among people with intellectual disability.

Michalski et al. [22] published one of the first studies demonstrating the effectiveness of IVR training for improving life skills among individuals with intellectual disability. In their within-groups study, participants were immersed in an HMD and completed a virtual waste management intervention. Performance in an equivalent real-world assessment indicated that participants significantly improved their real-world waste management skills following IVR training, to a moderate-to-large effect (*d* = 0.68). Encouragingly, the authors also found that skills were retained at a follow-up assessment one week later (*d* = 0.21) [22] Thus, Michalski et al. [22] provided preliminary support for the effectiveness of IVR for improving life skills among people with intellectual disability.

While preliminary evidence suggests promising outcomes, there are notable drawbacks associated with IVR in vulnerable populations. For instance, adverse effects such as cybersickness pose significant concerns regarding the suitability of IVR as a learning tool for people with intellectual disability [21]. In healthy populations, up to 16% of participants drop out of studies due to symptoms of cybersickness from using IVR, including eye strain, dizziness, and nausea [23]. Some research suggests that participants with neurodevelopmental disorders (such as Autism Spectrum Disorder) could be more affected by adverse effects than their neurotypical peers [24]. The current understanding of the prevalence of these adverse symptoms and their impact on skill acquisition among individuals with intellectual disability remains limited due to insufficient research. Past studies that have assessed IVR-induced cybersickness in populations with neurodevelopmental disorders have yielded substantial variations in prevalence rates, ranging from 13.8% to 83.3% of participants experiencing symptoms [24, 25]. Thus, perhaps there is a need to compare the effectiveness of IVR to lower-risk alternatives.

An alternative method for providing controlled and safe learning environments, without the risk of adverse side effects, is training using non-immersive virtual environments [21]. Non-immersive virtual environments such as tablets, desktops, or other flat-screen displays allow users to interact with the learning environment using a touchscreen display or via keyboard and mouse [26, 27]. Several studies have shown that training using non-immersive virtual environments can significantly improve real-world skills from pre- to post-training among individuals with intellectual disability [28, 29]. Although these devices are more widely adopted in educational settings and do not elicit adverse symptoms [24], they fail to facilitate the same level of realism and naturalness that IVR training provides [21, 30]. This raises the question of whether training in IVR or a non-immersive virtual environment would be more effective for developing skills in people with intellectual disability.

The current study aimed to compare the effectiveness of training in IVR and a non-immersive virtual environment for improving real-world skills in people with intellectual disability.. Building upon the methods used by Michalski et al. [22], this study assessed waste management skills. The real-world assessment was completed before (pre-test), after (post-test), and one-week after (delayed-test) virtual training in either immersive (HMD) or non-immersive (tablet) virtual environments. It was hypothesised that: (H1) skill performance, measured by total correct disposals in the real-world assessment at post-test, would be significantly higher in the IVR group compared to the non-immersive tablet group; (H2) skill retention, measured by total correct disposals in the real-world assessment at delayed-test, would be significantly higher in the IVR group compared to the non-immersive tablet group.

Method

Ethics

This study was granted ethics approval from the University of South Australia Human Research Ethics Committee (Protocol No. 202640).

Participants

Forty-one adults (21 male, 20 female) with an intellectual disability were recruited from a non-profit disability organisation in South Australia using a convenience sampling method. We recruited participants with any severity of intellectual disability. An a priori power analysis estimated that our sample would need 21 participants in each group for sufficient power (0.80) to detect a large effect (*d* > 0.8) with $\alpha = 0.05$ [31].

Participants were eligible to be included in the sample if they successfully passed the virtual tutorial which demonstrated adequate task understanding and motor capability to complete the subsequent virtual training. There were no restrictions on age, comorbid conditions, or motor abilities to be eligible for the study. Exclusion did occur if participants failed the tutorial, scored above 90% in the real-world assessment at pre-test due to insufficient room for improvement, or did not complete all virtual training sessions.

Five of the 41 participants recruited were excluded from the final sample. Reasons included failing the tutorial (*n* = 1), disinterest (*n* = 3) and feeling overwhelmed (*n* = 1). Therefore, 36 participants were included in the sample who were initially assigned to either the IVR group or the non-immersive tablet group using A-B-A-B sequencing. Participant characteristics are reported in Table 1.

Table 1

Participant Demographics in Both Virtual Environment Groups

Participant characteristics	IVR group (*n*=18)	Non-immerse tablet group (*n*=18)
Age (in years)		
Mean (*SD*)	37.2 (17.1)	36.8 (13.7)
Range	21-75	20-59
Gender		
Male	11	9
Female	7	9

Adaptive Functioning Level[a] (GAC standardised score) (*n*)		
71-79 GAC (Low)	2	3
<71 GAC (Extremely Low)	16	15
Mean GAC (*SD*)[b]	60.03 (5.19)	62.38 (10.89)
Comorbidities (*n*)		
Autism Spectrum Disorder	3	2
Down Syndrome	7	7
Fragile X Syndrome	1	0
Cerebral Palsy	0	2
Prader-Willi Syndrome	0	1
Mobility or Speech Issues	2	1
None or Not Reported	5	5

Note. Descriptive classification of adaptive functioning level included extremely low (<71), low (71-79), below average (80-89), average (90-109), above average (110-119), and high (120 or more) [32]. [a]Adaptive functioning level was measured using the GAC standardised score provided by the ABAS-III [32]. [b]No significant difference (p = .424) in GAC standardised score between both groups.

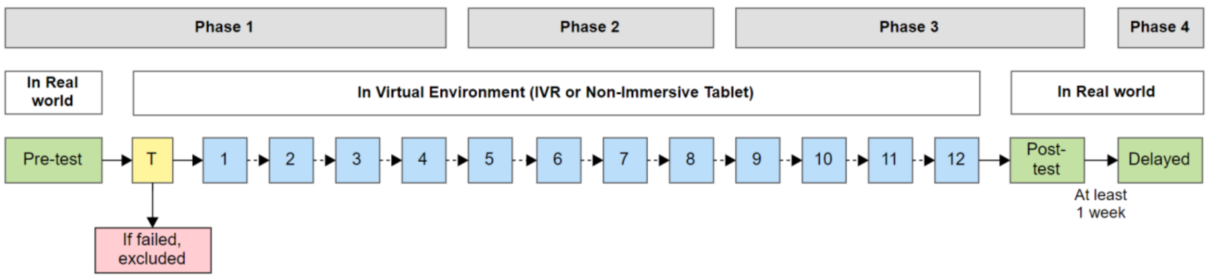
Design

A between-group longitudinal design was used to test the research hypotheses. The two experimental groups included the IVR group and the non-immersive tablet group.

Both groups completed the real-world assessment, the virtual tutorial, and 12 virtual training sessions across four data collection phases, as shown in Figure 1. The predictor variables for the main analysis included the virtual environment (IVR or non-immersive tablet) and real-world assessment timepoint (pre, post and delayed). The outcome variable was performance in the Real-World Assessment, measured by total correct disposals.

Figure 1

Study Timeline for Both Virtual Environment Groups



Note. Participants completed the real-world assessment at pre-test, post-test, and delayed-test timepoints. The virtual tutorial (T) and all 12 virtual training sessions (S1 – S12) were completed using either the IVR head-mounted display or tablet, depending on group assignment. Phase 1 to 4 represents each time the researchers collected the data. The time period between each phase varied due to staff availability. The aim was to complete two phases per week. Participants were not included in the sample if they failed the virtual tutorial after a maximum of three attempts. A delay of at least one week occurred between completing the real-world assessment at post-test and delayed-test.

Materials and Measures

Questionnaires and Assessments

Adaptive Behaviour Assessment System Third Edition (ABAS-III). The standardised ABAS-III was used to assess and classify participants' level of adaptive functioning (extremely low to high). [32]. The adult form of the ABAS-III was completed by organisation staff (*n*=2) who frequently interacted with the participant being assessed. Staff provided scores of observed ability between zero (not able) to three (always or almost always able) on a list of 11 skill areas, such as verbal communication. Scores were combined to form the General Adaptive Composite (GAC) standarddised score (ranging from 40 to 160) [32].

Cybersickness Questionnaire. Cybersickness was assessed using a questionnaire that read, “I felt dizzy or sick.” Participants were required to select one of three potential answers “yes”, “not sure”, “no” with matching emoticons to indicate level of sickness. This questionnaire with simplified graphics was developed by Michalski, Szpak [33] to assess symptoms of cybersickness from IVR among individuals with intellectual disability.

Hardware and Equipment

Meta Quest 2. The Quest 2 (developed by Meta; https://www.meta.com/au/quest/) HMD was used to display the virtual environment in the IVR group. The Quest 2 has a refresh rate of 90 Hz and a resolution of 1832x1920 per eye. This device uses inside-out motion tracking to detect direction and positioning of the user’s body. One wireless Quest 2 controller held in the dominant hand was used to enhance tracking for movements of the arm and hand.

Lenovo M10 Tablet. The Lenovo M10 (developed by Lenovo; https://www.lenovo.com/au/en/p/tablets /android-tablets/tab-series/lenovo-tab-m10/) was used to display the virtual environment in the non-immersive tablet group. The M10 has a 10.1" LED touchscreen display and Android 10 operating system.

Items. Twenty-four household items were included in the real-world assessment. The items were classified as ‘recycling,’ ‘general’ or ‘garden and food organics,’ based on South Australian guidelines. Eighteen (six per bin) of those items were digitally replicated and included in the virtual training sessions, as summarised in Table 2.

Table 2

Items in the Real-World Assessment and Virtual Training Split by Bin Type

Items	General Waste	Recycling	Garden and Food Organics
In virtual training and real-world assessment			

	Disposable coffee cup	Deodorant can	Orange
	Plastic bag	Cereal box	Apple
	Plastic cup	Glass coke bottle	Carrot
	Chocolate wrapper	Empty tin	Green tea bag
	Chips packet	Newspaper	Empty pizza box
	CD	Energy drink can	Green leaves
In real-world assessment only			
	Plastic straw	Plastic water bottle	Tree branch
	Plastic spoon	Magazine	Potato

Note. Waste classification was based on South Australian Council guidelines.

Real-World Assessment. All 24 items listed in Table 2 were randomly spread out on a table placed in front of three labelled bin options, as shown in Figure 2. Participants were instructed to dispose each item one-by-one into the bin that they thought correctly matched the item until all items were disposed. A tally of total correct disposals was recorded and ranged from 0 (no items in correct bins) to 24 (all items in correct bins).

Figure 2

Layout of the Real-World Assessment

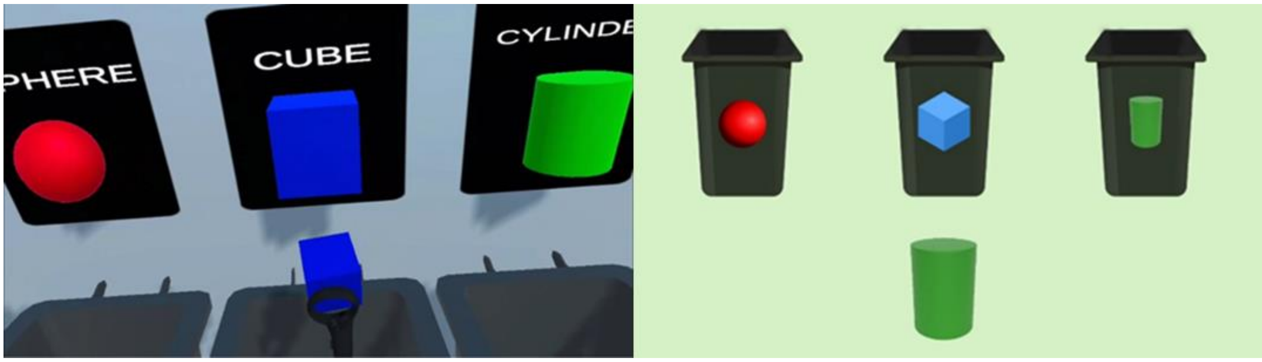
Software and Applications

The virtual tutorial and training applications were custom-designed using Unity 3D game engine (Unity Technologies; http://unity3d.com) and Javascript (Oracle; https://developer.oracle.com/languages/javascript.html) for the Quest 2 and Lenovo tablet, respectively.

Virtual Tutorial. The tutorial displayed nine objects of different shapes one-by-one on a table adjacent to three bin options with matching labels (see Figure 3). Participants had to correctly dispose eight of the nine objects in the matching bin to pass the tutorial. In the IVR group, virtual objects could be grabbed and disposed by holding and releasing the trigger button on the controller which required movement of the whole body to transport objects from the table to the bins. In the tablet group, grabbing and disposing the objects required tapping and dragging the touchscreen using a fingertip.

Figure 3

Virtual Tutorial in Both Virtual Environments

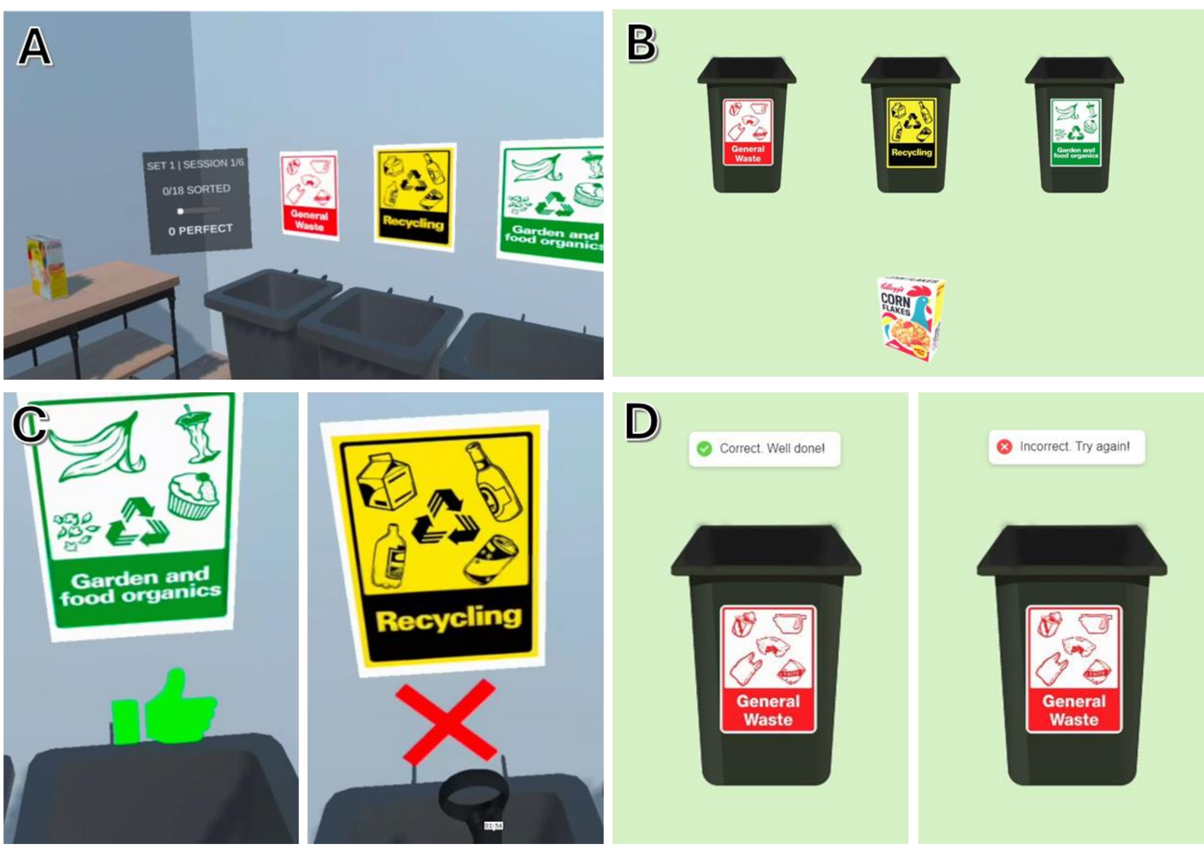


Note. A screenshot of the tutorial is shown from within the IVR head-mounted display (left) and non-immersive tablet (right).

Virtual Training. The virtual training task used in each training session replicated the Real-World Assessment in all components besides the number of items. In virtual training, only 18 items were presented (see Table 1). The virtual interactions in the training task were identical to the virtual tutorial, and feedback on performance was provided (see Figure 4).

Figure 4

Virtual Training and Feedback in Both Virtual Environments

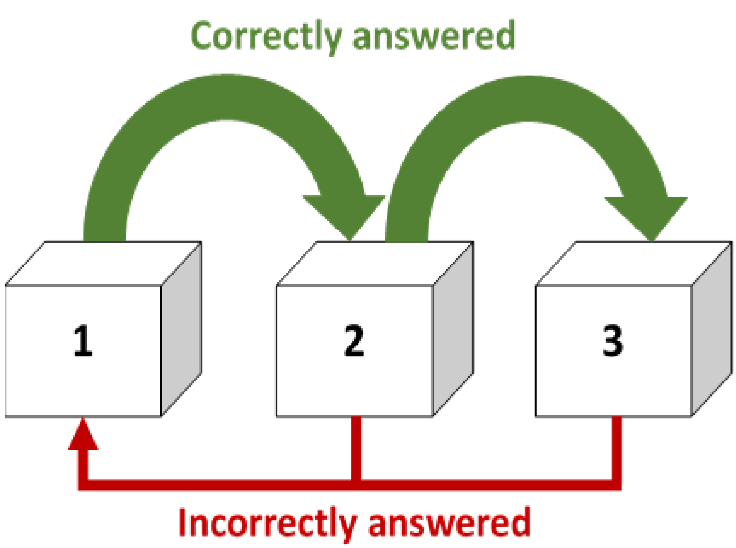


Note. A screenshot of the virtual training task is shown from within the (A) IVR head-mounted display and (B) non-immersive tablet. A screenshot of the visual feedback presented after each disposal is also shown from within the (C) IVR head-mounted display and (D) non-immersive tablet. This feedback appeared after each disposal and indicated to the participant whether the disposal was correct or incorrect.

The frequency of each item appearing varied in each virtual training session and was based on the principles of spaced repetition using the Leitner System [34]. The Leitner system is one of the earliest and most widely used models of spaced repetition which illustrates the optimal frequency of repetition using a multi-box arrangement (see Figure 5) (Beursgens, 2022; Leitner, 1972). Past research has shown the enhanced effectiveness of spaced repetition for improving learning outcomes compared to non-spaced learning schedules among individuals with developmental learning disability [35-38].

Figure 5

Presentation Frequency of Items in Virtual Training



Note. All items began in box 1 in the first virtual training session. Items in box 1 were shown at the highest frequency (shown every session). If an item in box 1 was correctly disposed in a virtual training session, the frequency of that item appearing reduced and moved to box 2 frequency (shown every second session), and this process repeated with box 3 (every third session). If an item in box 2 or 3 was incorrectly disposed in a subsequent virtual training session, the item returned back to appearing every session (box 1). The box algorithm reset and all items returned to box 1 frequency upon completion of the first six training sessions.

Procedure

A simplified informed consent form was signed by each participant and a staff member also signed to confirm the mental capacity of the participant to consent.

Real-World Assessment (Pre-test)

The real-world assessment was set up in a 10 m x 5 m room, shown in Figure 2. Each participant was allowed one disposal attempt per item and no further instruction or feedback was provided until all items in the task were disposed.

Virtual Tutorial

A researcher then assisted the participants to either fit on the Quest 2 HMD, or setup the Lenovo M10 device, depending on group allocation. Participants were assessed using the cybersickness questionnaire after completing the tutorial. For participants who reported feeling cybersickness, further questioning occurred to confirm their desire to continue the study. Upon passing, participants immediately began the first virtual training session.

To successfully pass the VR tutorial, participants were required to correctly place at least eight out of nine items into the designated bins. Those who failed to meet this criterion after a maximum of three attempts were excluded from the study. The tutorial was deemed incomplete if participants remained unresponsive in VR, failed to follow the task instructions, or did not press the necessary button at the correct time, despite several reminders. Throughout the tutorial, a researcher was on hand to offer reminders and assistance. Participants who successfully completed the VR tutorial advanced to the next phase, the VR training.

Virtual Training

Participants completed 12 virtual training sessions in total. Each virtual training session ended once all items were correctly disposed into the bins. Participants completed four training sessions per day. After every second training session, participants were assessed using the cybersickness questionnaire. Although the spacing between training sessions varied due to staff availability, the aim was to complete four virtual training sessions per week.

Real-World Assessment (Post and delayed-test)

Immediately following the last virtual training session, participants completed the real-world assessment again (post-test). One week later, participants completed the same real-world assessment (delayed-test).

Statistical Analyses

The data was screened for normality and appropriate diagnostic tests were run before all inferential tests.

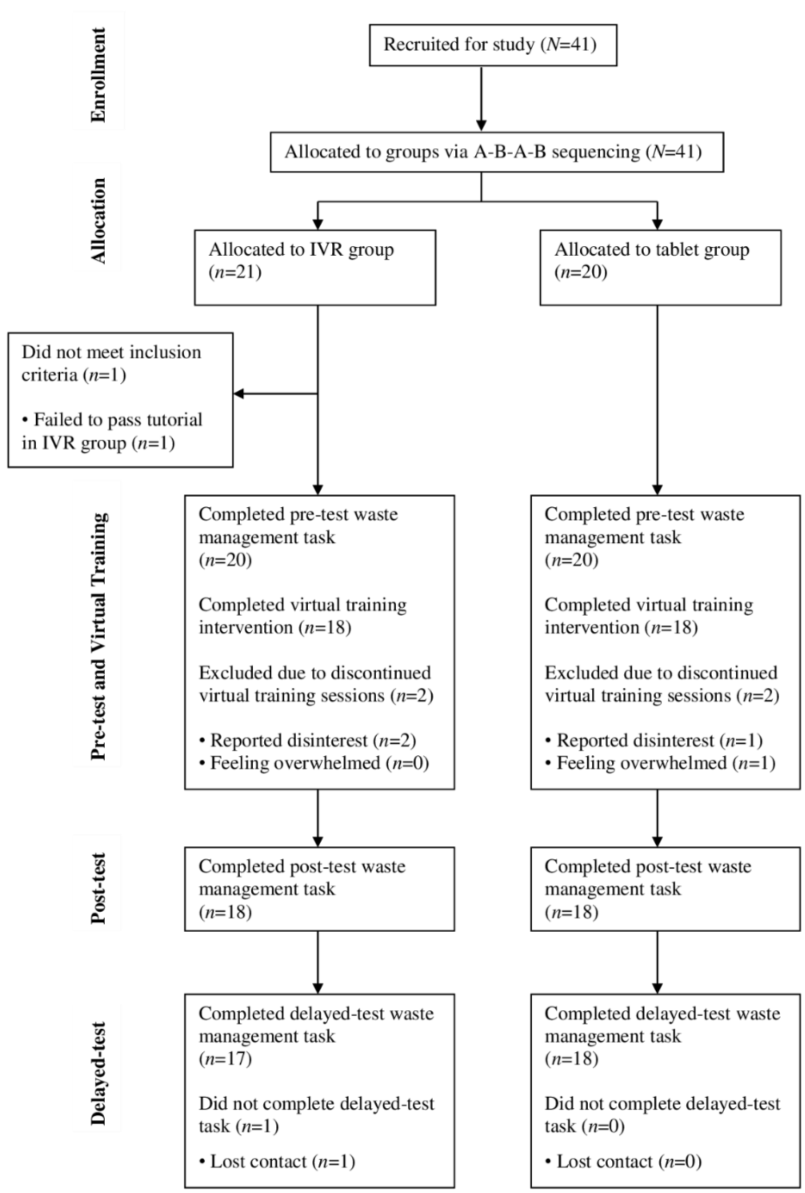
A linear mixed-effects regression was run to examine performance differences in the Real-World Assessment between both groups, using the GAMj package in Jamovi (Gallucci, 2019). Total correct disposals in the real-world assessment (counts ranging from 0-24) was entered as the discrete outcome variable; virtual environment group with two levels (IVR and non-immersive tablet), real-world assessment timepoint with three levels (pre, post and delayed), and real-world task timepoint by virtual environment group interaction were entered as fixed effects; and participants were included as the random intercept effect. Significant main and interaction effects (significance cutoff $p < 0.05$) were followed up with Bonferroni-Holm corrected post hoc comparisons to test H1 and H2. Cohen's d effect sizes and confidence intervals were calculated using raw data and the Esci package in Jamovi [39].

Results

Five of the 41 recruited participants were excluded from the sample, as seen in the adapted CONSORT flow diagram in Figure 6 [40].

Figure 6

Participant Flow Diagram



All 36 included participants completed the real-world assessment at pre-test and post-test, and completed all virtual training sessions. One participant in the IVR group did not complete the real-world assessment at delayed-test due to lost contact. No other missing entries or extreme outliers were identified.

Virtual Training Descriptives

All participants completed 12 virtual training sessions. The average training session lasted 3.1 minutes (SD = 2.47) in the IVR group and 2.5 minutes (SD = 1.77) in the non-immersive tablet group. The entire virtual training intervention was completed (first session to last) in an average of 16.3 days (SD = 14.4) in the IVR group and 8.6 days (SD = 6.6) in the non-immersive tablet group. The mean difference in days to complete training between both groups (*M* = 12.45, *SD* = 10.5) was due to random variation in participants' and staff availability. An independent samples t-test revealed that this difference was statistically significant ($t = 2.06$, $p = .046$).

Real-World Assessment Descriptives

The mean duration in days between the real-world assessment at pre-test and post-test was 17 days (*SD* = 19) for the IVR group and 12.72 days (*SD* = 10.22) for the non-immersive tablet group. Between post and delayed-test, the mean duration was 7.66 days (*SD* = 2.96) for the IVR group and 9.5 days (*SD* = 7.12) for the non-immersive tablet group. A pair of independent samples t-tests revealed no significant between-group differences in days between the real-world assessment at pre to post-test ($p = .406$, $d = -0.27$) or post to delayed-test ($p = .318$, $d = 0.33$).

Real-World Assessment Analysis

Diagnostic tests did not reveal any assumption violations for the regression.

A linear mixed-effects regression revealed significant main effects of virtual environment group ($F_{1,34.0} = 8.93$, $p = .005$), real-world assessment timepoint ($F_{2,67.1} = 12.34$, $p < .001$), and a significant interaction effect between both fixed factors ($F_{2,67.1} = 4.56$, $p = .014$) on total correct disposals in the real-world assessment. Table 3 summarises the between and within-group post hoc comparisons.

Table 3

Differences in Correct Disposals in the Real-World Assessment *Between and Within-Groups*

Comparison type	Group	Time comparison	Mean difference	*t* (df)	Corrected *p* value	Cohen's *d*
Between-Group	IVR vs TAB					
		Pre-test	2.50	1.70 (34)	.288	0.61
		Post-test	4.78	3.25 (34)	.012*	1.00
		Delayed-test	5.21	3.38 (33)	.007**	1.12
Within-Group	IVR					
		Pre vs Post	3.34	5.18 (17)	.007**	1.20
		Post vs Delayed	-0.24	-0.36 (16)	.970	-0.05
		Pre vs Delayed	2.92	4.05 (16)	.005**	0.77
	TAB					
		Pre vs Post	1.06	0.62 (17)	.542	0.20
		Post vs Delayed	-0.66	-0.35 (17)	.732	-0.11
		Pre vs Delayed	0.39	0.26 (17)	.798	0.08

Note. Cohen's d effect size interpretation: 0.2 = small effect size; 0.5 medium effect size; 0.8 large effect size. Instances of negative t-values indicate higher scores in time one than time two. Bonferroni- holm correction was applied to the alpha values to counteract family-wise error rates.

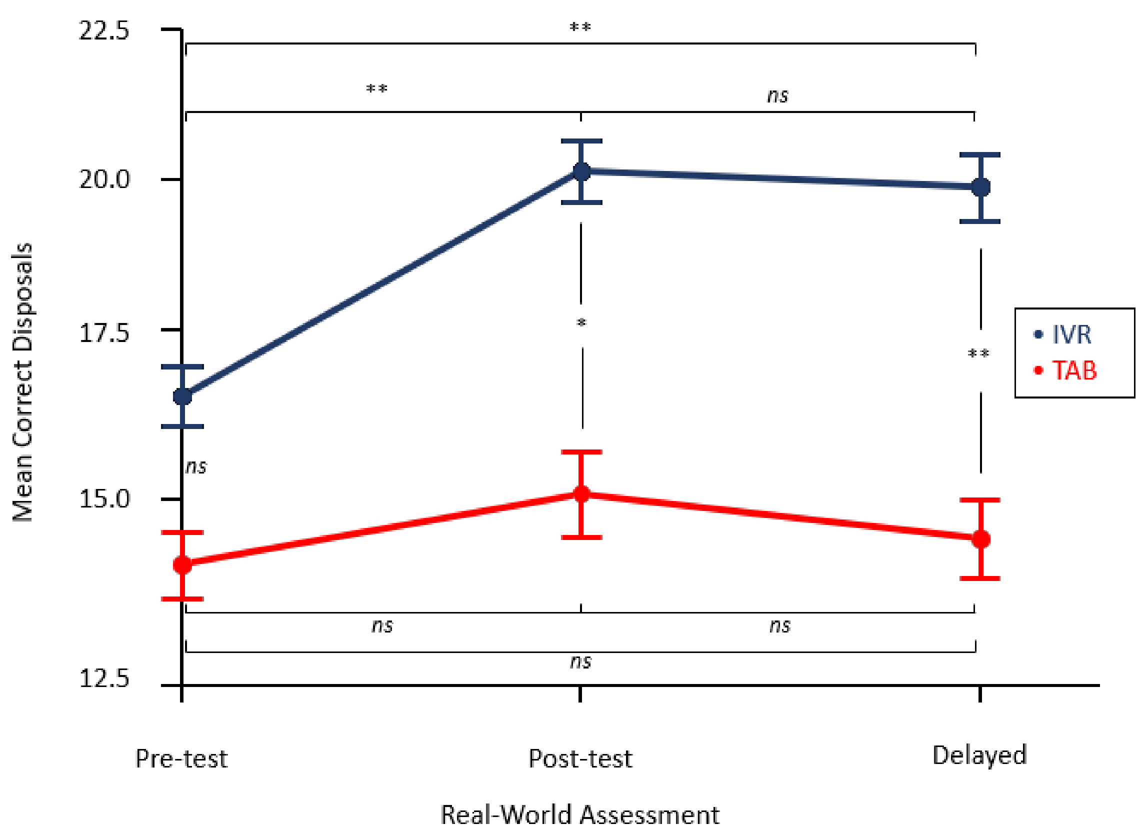
*p < .05, **p < .01.

H1 was supported by the IVR group showing significantly more correct disposals in the real-world assessment at post-test compared to the non-immersive tablet group, as seen in Table 3. This effect was large as indicated by *d* = 1.00, 95% CI [0.34, 1.79].

H2 was supported by the IVR group showing significantly more correct disposals in the real-world assessment at delayed-test compared to the non-immersive tablet group. This effect was large as indicated by *d* = 1.12, 95% CI [0.45, 1.94]. There was also no significant between-group difference (*p* = .288, *d* = 0.61) at pre-test, as shown in Figure 7.

Figure 7

Correct Disposals in the Real-World Assessment *Across Timepoints and Between Groups*



Note. Circular points on each line represent the mean correct disposals in the Real-World Assessment, and the error bars represent the standard error for each mean. The blue line represents the IVR group, and the red line represents the non-immersive tablet group.

Significance testing completed using Bonferroni-holm corrected post hoc comparisons. Non-significant comparisons using an alpha cutoff value of $p < .05$ were labelled by ns. Significant comparisons were labelled $*p < .05$, $**p < .01$.

Adaptive Functioning

Multiple Pearson correlations revealed no significant relationship between adaptive functioning level and change in real-world assessment performance in the IVR group. In the tablet group, a significant correlation between adaptive functioning and change in correct disposals in the real-world assessment was found between pre to post-test. No other significant associations were found, as seen in Table 4.

Table 4

Correlations Between Adaptive Functioning and Change in Real-World Assessment *Performance*

Group	Time comparison	*r*	*p* value
IVR			
	Pre-to-post	-0.157	.547
	Pre-to-delayed	0.003	.992
	Post-to-delayed	0.025	.926
TAB			
	Pre-to-post	0.570	.021*
	Pre-to-delayed	0.454	.077
	Post-to-delayed	-0.343	.194

Note. Task performance = correct disposals, Adaptive Functioning = General Adaptive Composite, *p < .05.

Cybersickness

Cybersickness was assessed across all participants after each virtual tutorial and every second training session, totalling 252 assessments. Three (16.7%) of the participants in the IVR group answered “not sure” at least once and one participant (5.56%) answered “yes” to feeling cybersickness, and reported feeling “dizzy.” However, symptoms subsided within a few minutes and all four participants completed the training sessions. The remaining 14 participants in the IVR group, and all participants in the non-immersive tablet group, reported no symptoms.

Discussion

This study contributes to the existing literature by examining the effectiveness of immersive versus non-immersive virtual environments [41], specifically in enhancing real-world life skills among people with intellectual disability. Identifying effective learning methods for safely developing life skills is crucial for enabling more individuals with intellectual disability to progress toward independent living, which is associated with better psychosocial outcomes [6]. Consistent with our hypotheses, our findings showed that the IVR group scored significantly more correct disposals in the real-world assessment at post-test and delayed-test, compared to the non-immersive group. The effect sizes for the between-group comparisons at both timepoints were large. Further analyses also showed that the IVR group, but not the non-immersive group, significantly increased correct disposals in the real-world assessment across timepoints. These findings indicate that training in IVR was more effective than the non-immersive virtual environment for improving and retaining waste management skills among people with intellectual disability.

Our novel findings support and extend past literature that has shown the benefits of experiential learning for developing real-world skills among individuals with intellectual disability [7, 9, 11-13]. The IVR training used in the present study closely replicated the three-dimensional environment and physical movements required in the real-world assessment. In contrast, training in the non-immersive virtual environment required users to touch and drag a fingertip on the tablet. Our findings indicate that the opportunity for realistic and hands-on practice in IVR training facilitated better skill learning among people with intellectual disability, suggesting that the benefits of experiential learning observed in real-world environments also apply in virtual environments. However, it is also possible that extraneous factors such as engagement, view of environmental distractions, sense of presence (feeling of 'being there'), and motivation may have impacted the observed differences in real-world performance [42, 43]. For example, IVR is reported to be more engaging and motivating than non-immersive virtual environments for individuals with learning difficulties [43, 44], and this is associated with better skill learning [43]. Although research has shown the benefits of IVR while controlling for factors such as motivation [20], future studies are encouraged to replicate these findings in people with intellectual disability to more accurately assess the role of experiential learning in improving skills using IVR.

Further analyses revealed that the IVR group significantly increased their performance in the real-world assessment across timepoints, whereas the non-immersive tablet group showed no significant changes. This is consistent with the singular past study that investigated the effectiveness of IVR for improving real-world waste management skills among people with intellectual disability [22]. However, Michalski et al. [22] reported medium sized effects of IVR training in their study, whereas the current study identified large effects. One interesting aspect of the current study's findings relate to observed differences across the post-test and delayed-test assessments. The IVR group exhibited not only an immediate improvement in real-world waste management skills from pre- to post-training but also retained these skills effectively at the one-week follow-up. This contrasts with the non-immersive tablet group, which showed minimal improvement over time. The lack of change in the non-immersive group could be attributed to the less engaging nature of the training medium for learning. These observations are pivotal as they underscore the importance of the immersive quality of the training environment in enhancing not only the acquisition but also the persistence of new skills in people with intellectual disability.

One major difference between the two studies was the type of learning paradigm implemented in the design of the virtual training. Michalski et al. [22] used a simple paradigm of learning via repetition, whereby the time-period between correctly disposed items appearing in the virtual training was fixed (one-session intervals). In contrast, the current study implemented the principles of spaced repetition by designing the virtual training using the Leitner system [34]. This meant that correctly disposed items were shown at increasing intervals across the virtual training sessions in our study. Foundational research in psychology states that repetitions spaced across larger periods of time result in enhanced memory and learning compared to repetitions massed closer together, known as the spacing effect [45, 46]. Research also shows that this spacing effect is observed in populations with learning difficulties, despite deficits in intellectual functioning [35-37]. Therefore, the larger effects found in our study may suggest that spaced repetition is effective for enhancing real-world skill development from IVR training in people with intellectual disability.

This study is one of the first to compare the effectiveness of an immersive and non-immersive virtual environment for improving real-world life skills among individuals with intellectual disability. Our findings support past literature that has demonstrated the benefits of experiential learning for developing skills among individuals with intellectual disability. The benefits identified in this study align with the task-technology fit model, which posits that the effectiveness of the technology is maximised when the capabilities of the technology align closely with the demands of the task it is intended to support [47, 48]. For learners with intellectual disability, the immersive and interactive features of IVR are particularly suited to enhance experiential learning, which is crucial for engagement and retention of information. The IVR application engaged users through spatial awareness and motor coordination that is more challenging to implement when using traditional, non-immersive technologies. In our study, the alignment between the IVR's capabilities and the demands of the task demonstrated a good task-technology fit compared to tablet-based learning. The importance of such an alignment was convincingly highlighted in a meta-analysis by Howard et al. [49], which identified task-technology fit as a significant moderator influencing the effectiveness of VR training programs. Their findings show that suboptimal task-technology fit reduces the effectiveness of VR training, suggesting that VR might not always be the best training medium depending on the task and context.

Given the small sample size and variability in symptom reporting, it is important to interpret these findings cautiously. Although our study indicated that most participants in the IVR group completed the virtual training sessions, and only one (5.56%) participant reported minor symptoms of cybersickness, this does not necessarily guarantee similar outcomes in broader applications. Studies have observed varying levels of cybersickness (Glaser et al., 2022; Newbutt et al., 2016; Michalski et al., 2023) suggesting that factors such as the IVR content's nature, visual stimulation levels, locomotion patterns, and exposure duration significantly influence symptom prevalence . Additionally, discrepancies in reporting methods and questionnaire could impact reported rates of cybersickness. The small sample size in our study limits our ability to adequately covary for comorbidities and sensory differences among participants. Future research should focus on recruiting larger and more diverse samples to better control for potentially confounding variables.

While IVR offers promising advancements in skill training for people with intellectual disability, it is crucial to consider the limitations and practical challenges associated with its use. It is important to acknowledge real-world risks that are not entirely mitigated by the virtual setting. Notably, individuals may still encounter physical risks such as colliding with walls or striking hands-on tables or countertops during IVR sessions. . While, IVR hardware is becoming increasingly more affordable [50], there also remains concern from professionals and informal caregivers regarding the practical applicability of IVR training in clinical and daily living settings. There is a steep learning curve required to use IVR which is perceived as a barrier its use by caregivers and healthcare professionals [51-53]. Another significant hurdle is that HMDs can prevent professionals from viewing the user's screen [54]. Implementing the casting feature, which streams the user's view to an external monitor, could enhance supervision and interaction during training. However, while such solutions do exist, disability support staff may lack the necessary training to effectively use VR [53].

Several design choices in this study must be acknowledged as potential limitations. First, the participants were all recruited from a specific geographic area and demographic, which may limit the generalisability of the findings to other populations with intellectual disabilities. Second, the sampling method involved convenience sampling, which might introduce selection bias as participants who are more readily available or willing to participate might differ in significant ways from those who are not. Third, the presentation of objects differed significantly across environments. Fourth, the study was unable to investigate other immersive VR programs that do not utilise headsets but may still engage users effectively. There are alternative immersive technologies, including projection-based systems or more interactive desktop environments, which could offer different benefits. Fifth, the tutorial was designed to familiarise participants with the tasks but might inadvertently introduce bias by priming participants to look for specific responses during the assessments. Finally, we were unable to control for length of the training sessions given the spaced repetition approach utilised, and interval between assessments.

A key consideration for future research is the number and length of training sessions required for effective skill learning in IVR [25, 55]. Several factors may impact the optimal amount of training including task complexity, capability of the population, and adverse symptoms such as cybersickness. To date, past literature shows a clear lack of consistency and explicit reporting of training duration in IVR research [55]. In a recent review of 330 studies using typically developed samples, almost half did not provide information on the duration of IVR training (including number and length of sessions) [55]. Their review also showed that there was a very large range in reported IVR training session lengths, ranging from 2 minutes up to 10 hours. A similar lack of consistency has been observed among studies in this population. More recently, however, Smith, Van Ryzin [56] explored the dosing efficiency and efficacy of virtual interview training for transition-age youth with disabilities, finding that a targeted number of completed training sessions could significantly enhance job interview skills and subsequent employment outcomes. Further, in Michalski et al. (2023), VR training sessions varied in number until participants reached a learning target or hit a maximum of ten sessions, with a median of 8.5 sessions. This flexible approach tailored the training dosage based on individual progress, effectively accommodating each participant's unique learning pace and needs. This method prevents premature termination or unnecessary prolonging of training. Specific attention to training dose is essential when designing IVR interventions, particularly for people with intellectual disability.

IVR shows considerable potential for broad application beyond its current use in building life skills among people with intellectual disability. Its ability to simulate realistic, interactive environments makes it adaptable for training across various contexts, such as vocational tasks, social interactions, and emergency responses. This adaptability could extend its benefits to broader populations, including those with other neurodevelopmental disabilities or in professional training settings. Although non-immersive virtual environments like tablets and desktops are widely used for their accessibility and lower risk of cybersickness, IVR's distinct advantages in enhancing engagement and providing a safe, controlled learning environment make it a promising tool. The efficacy of IVR hinges on overcoming challenges related to cybersickness and improving accessibility. However, it is important to recognise that IVR is not a universal solution. The appropriateness of technology must be carefully matched to the specific needs and contexts of the users. In some cases, simpler or more traditional methods may be equally effective and less burdensome for implementation.

References

1. Bridges, S.A., et al., *Augmented reality: Teaching daily living skills to adults with intellectual disabilities.* Journal of Special Education Technology, 2020. **35**(1): p. 3-14.
2. American Psychiatric Association. *Diagnostic And Statistical Manual Of Mental Disorders, Fifth Edition, Text Revision (DSM-5-TR)*. 2022; Available from: https://doi.org/10.1176/appi.books.9780890425787.
3. Balboni, G., et al., *Factors affecting the relationship between adaptive behavior and challenging behaviors in individuals with intellectual disability and co-occurring disorders.* Research in Developmental Disabilities, 2020. **104**: p. 103-118.
4. Australian Institute of Health and Welfare, *Intellectual disability in Australia. AIHW.* 2023.
5. Martin, A., et al., *The role of executive function in independent living skills in female adolescents and young adults with fragile X syndrome.* American journal on intellectual and developmental disabilities, 2016. **121**(5): p. 448-460.
6. Sandjojo, J., et al., *Promoting independence of people with intellectual disabilities: A focus group study perspectives from people with intellectual disabilities, legal representatives, and support staff.* Journal of Policy and Practice in Intellectual Disabilities, 2019. **16**(1): p. 37-52.
7. Wehmeyer, M.L. and K.A. Shogren, *Handbook of research-based practices for educating students with intellectual disability*. 2017: Routledge New York, NY.
8. Stavroussi, P., P.F. Papalexopoulos, and D. Vavougios, *Science education and students with intellectual disability: Teaching approaches and implications.* Problems of Education in the 21st Century, 2010. **19**: p. 103.
9. Swandewi, I.G.A.W.A., E. Wahyuno, and S. Sopingi, *Learning by Doing Methods in the Field of Horticultural Skills to Improve the Calculating Ability of Students with Intellectual Disability.* Jurnal Penelitian dan Pengembangan Pendidikan Luar Biasa, 2019. **6**(1): p. 19-24.
10. Kolb, D.A., R.E. Boyatzis, and C. Mainemelis, *Experiential learning theory: Previous research and new directions*, in *Perspectives on thinking, learning, and cognitive styles*. 2014, Routledge. p. 227-247.
11. Algahtani, F., *Teaching students with intellectual disabilities: Constructivism or behaviorism?.* Educational Research and Reviews, 2017. **12**(21): p. 1031-1035.
12. Foti, F., et al., *Learning by observation and learning by doing in Prader-Willi syndrome.* Journal of Neurodevelopmental Disorders, 2015. **7**: p. 1-12.

13. Scruggs, T.E., et al., *Reading versus doing: The relative effects of textbook-based and inquiry-oriented approaches to science learning in special education classrooms.* The Journal of Special Education, 1993. **27**(1): p. 1-15.
14. Huang, P. and D. Durbin, *Promoting safety in children with disabilities.* UpToDate, 2023.
15. Ioanna, D., *Independent living of individuals with intellectual disability: a combined study of the opinions of parents, educational staff, and individuals with intellectual disability in Greece.* International Journal of Developmental Disabilities, 2020. **66**(2): p. 153-159.
16. Calver, J., R. Balogh, and D. Rudoler, *Incidence of injury in children and adolescents with intellectual and developmental disability.* Journal of safety research, 2021. **77**: p. 56-60.
17. Kwon, C., *Verification of the possibility and effectiveness of experiential learning using HMD-based immersive VR technologies.* Virtual Reality, 2019. **23**(1): p. 101-118.
18. Marougkas, A., et al., *Virtual Reality in Education: A Review of Learning Theories, Approaches and Methodologies for the Last Decade.* Electronics, 2023. **12**(13): p. 2832.
19. Farr, A., et al., *Skill retention after desktop and head-mounted-display virtual reality training.* Experimental Results, 2023. **4**(2).
20. Ratcliffe, J. and L. Tokarchuk. *Presence, embodied interaction and motivation: distinct learning phenomena in an immersive virtual environment*. in *Proceedings of the 28th ACM International Conference on Multimedia*. 2020.
21. Zhou, C., H. Li, and Y. Bian, *Identifying the optimal 3d display technology for hands-on virtual experiential learning: a comparison study.* IEEE access, 2020. **8**: p. 73791-73803.
22. Michalski, S.C., et al., *Improving real-world skills in people with intellectual disabilities: an immersive virtual reality intervention.* Virtual Reality, 2023: p. 1-12.
23. Saredakis, D., et al., *Factors associated with virtual reality sickness in head-mounted displays: a systematic review and meta-analysis.* Frontiers in human neuroscience, 2020. **14**: p. 96.
24. Glaser, N., M. Schmidt, and C. Schmidt, *Learner experience and evidence of cybersickness: design tensions in a virtual reality public transportation intervention for autistic adults.* Virtual Reality, 2022. **26**(4): p. 1705-1724.
25. Michalski, S.C., et al., *Improving real-world skills in people with intellectual disabilities: An immersive virtual reality intervention.* Virtual Reality, 2023.
26. Haßler, B., L. Major, and S. Hennessy, *Tablet use in schools: a critical review of the evidence for learning outcomes.* Journal of Computer Assisted Learning, 2016. **32**(2): p. 139-156.
27. Sousa, C.V., et al., *Active video games in fully immersive virtual reality elicit moderate-to-vigorous physical activity and improve cognitive performance in sedentary college students.* Journal of Sport and Health Science, 2022. **11**(2): p. 164-171.
28. Hansen, D.L. and R.L. Morgan, *Teaching grocery store purchasing skills to students with intellectual disabilities using a computer-based instruction program.* Education and Training in Developmental Disabilities, 2008: p. 431-442.
29. Brooks, B., et al., *An evaluation of the efficacy of training people with learning disabilities in a virtual environment.* Disability and rehabilitation, 2002. **24**(11-12): p. 622-626.
30. Malihi, M., et al., *Evaluating the safety and usability of head-mounted virtual reality compared to monitor-displayed video for children with autism spectrum disorder.* Autism, 2020. **24**(7): p. 1924-1929.
31. Faul, F., et al., *G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences.* Behavior Research Methods, 2007. **39**(2): p. 175-191.
32. Prokopiak, A. and J. Kirenko, *ABAS-3–An instrument for assessing adaptive skills in people with an intellectual disability.* Hrvatska revija za rehabilitacijska istraživanja, 2020. **56**(2): p. 154-168.
33. Michalski, S.C., et al., *Using virtual reality to improve classroom behavior in people with down syndrome: Within-subjects experimental design.* Journal of Medical Internet Research and Serious Games, 2022. **10**(2): p. 34-37.
34. Leitner, S., *So lernt man Lernen: Der Weg zum Erfolg [Learning to learn: The road to success].* Freiburg: Herder, 1972.

35. Haebig, E., et al., *Retrieval-based word learning in young typically developing children and children with development language disorder II: A comparison of retrieval schedules.* Journal of Speech, Language, and Hearing Research, 2019. **62**(4): p. 944-964.
36. Leonard, L.B., et al., *A multi-study examination of the role of repeated spaced retrieval in the word learning of children with developmental language disorder.* Journal of Neurodevelopmental Disorders, 2021. **13**(1): p. 20.
37. Leonard, L.B., et al., *The contributions of immediate retrieval and spaced retrieval to word learning in preschoolers with developmental language disorder.* Autism & developmental language impairments, 2022. **7**: p. 23969415221077652.
38. Tabibian, B., et al., *Enhancing human learning via spaced repetition optimization.* Proceedings of the National Academy of Sciences, 2019. **116**(10): p. 3988-3993.
39. Calin-Jageman, R.J. and G. Cumming, *The new statistics for better science: Ask how much, how uncertain, and what else is known.* The American Statistician, 2019. **73**(sup1): p. 271-280.
40. Schulz, K.F., D.G. Altman, and D. Moher, *CONSORT 2010 statement: updated guidelines for reporting parallel group randomized trials.* Ann Intern Med, 2010. **152**(11): p. 726-32.
41. Carreon, A., et al., *Comparing immersive VR and non-immersive VR on social skill acquisition for students in middle school with ASD.* Journal of Research on Technology in Education, 2023: p. 1-14.
42. Cheng, Y., C.-L. Huang, and C.-S. Yang, *Using a 3D immersive virtual environment system to enhance social understanding and social skills for children with autism spectrum disorders.* Focus on Autism and Other Developmental Disabilities, 2015. **30**(4): p. 222-236.
43. Halabi, O., et al., *Design of Immersive Virtual Reality System to Improve Communication Skills in Individuals with Autism.* International Journal of Emerging Technologies in Learning, 2017. **12**(5).
44. Lambert, R. and T. Sugita, *Increasing engagement of students with learning disabilities in mathematical problem-solving and discussion.* Support for Learning, 2016. **31**(4): p. 347-366.
45. Ebbinghaus, H., *Über das gedächtnis: untersuchungen zur experimentellen psychologie*. 1885: Duncker & Humblot.
46. Hintzman, D.L., *Theoretical implications of the spacing effect.* 1974.
47. Fuller, R.M. and A.R. Dennis, *Does fit matter? The impact of task-technology fit and appropriation on team performance in repeated tasks.* Information Systems Research, 2009. **20**(1): p. 2-17.
48. McGill, T.J. and V. Hobbs, *How students and instructors using a virtual learning environment perceive the fit between technology and task.* Journal of Computer Assisted Learning, 2008. **24**(3): p. 191-202.
49. Howard, M.C., M.B. Gutworth, and R.R. Jacobs, *A meta-analysis of virtual reality training programs.* Computers in Human Behavior, 2021. **121**: p. 106808.
50. Boeldt, D., et al., *Using virtual reality exposure therapy to enhance treatment of anxiety disorders: identifying areas of clinical adoption and potential obstacles.* Frontiers in psychiatry, 2019. **10**: p. 773.
51. Bell, I.H., et al., *Virtual reality as a clinical tool in mental health research and practice* Dialogues in Clinical Neuroscience, 2020. **22**(2): p. 169-177.
52. Chung, O.S., et al., *Are Australian mental health services ready for therapeutic virtual reality? An investigation of knowledge, attitudes, implementation barriers and enablers.* Frontiers in Psychiatry, 2022. **13**: p. 792663.
53. Cricelli, G., et al., *Implementation of Virtual Reality for Neurodivergent Individuals: Perspectives of Disability Care Staff.* PsyArXiv, 2024.
54. Nwosu, A.C., et al., *Virtual reality in specialist palliative care: a feasibility study to enable clinical practice adoption.* BMJ supportive & palliative care, 2021.
55. Strojny, P. and N. Dużmańska-Misiarczyk, *Measuring the effectiveness of virtual training: A systematic review.* Computers & Education: X Reality, 2023. **2**: p. 100006.

56. Smith, M.J., et al., *Virtual Job Interview Training: A Dose Response to Improve Employment for Transition-Age Youth With Disabilities.* Career Development and Transition for Exceptional Individuals, 2023: p. 21651434231160532.