Inclusive Virtual Reality Learning: Review and 'Best-Fit' Framework for Universal Learning

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Abstract: The rise of Virtual Reality (VR) in educational contexts has highlighted the need to design Virtual Reality Learning Applications (VRLAs) that prioritize inclusivity, accommodating a spectrum of learner needs. Despite the surging interest, there is a noticeable gap in research that delves into the specifics of creating VRLAs that are rooted in inclusive educational theory. This research sought to extract insights and recommendations for the development of VRLAs tailored for diverse student populations. The intention was to scrutinize research focused on the inclusive design elements of VRLAs, leading to the establishment of preliminary Inclusion Guidelines for VR Learning (IGVRL). Adopting the "best-fit" framework synthesis technique, the research anchored its findings in the Universal Design for Learning (UDL) framework. UDL was developed to mold learning experiences to meet the requirements of heterogenous learners. Using UDL as a coding framework, a comprehensive literature review was undertaken, adhering to the SPIDER search strategy. The review of literature revealed distinct design recommendations that facilitate inclusive learning within VRLAs. Information was systematically categorized based on UDL's nine classifications and subsequently distilled into the preliminary IGVRL. It's pertinent to note that these guidelines, while offering a foundational perspective, necessitate further in-depth evaluations for validation. The analytical process brought to the fore several themes that UDL did not adequately encompass, such as the nuances of embodied learning, the focus on VR contents and their immersive properties, and the pivotal role of collaboration and cooperation in VRLAs. These insights underscore the further need for research in these areas. Although some facets of VR accessibility were discussed, a deeper exploration into this domain was identified as crucial, reiterating the importance of accessibility in underpinning inclusive education. The research underscores the potential of VRLAs in promoting inclusivity within educational settings and introduces the preliminary IGVRL for VRLA design, specifically targeting K-12 contexts. This paper emphasizes the continuum of research required to refine and validate these guidelines, ensuring their applicability and efficacy in diverse educational scenarios.

Keywords: Inclusion, Virtual reality, Development, Guidelines, Design, UDL

1. Introduction

In recent years, the advancement of Virtual Reality (VR) technology has generated increased interest in its potential applications within education (Kasperiuniene and Faiella, 2023; Sulistyaningrum et al., 2022). However, many studies overlook the specifics of designing Virtual Reality Learning Applications (VRLAs), focusing instead on the overall effectiveness of VR (Hamilton et al., 2021).

VR, as defined by Dörner et al., 2019, entails computer-generated, three-dimensional environments that provide users with an immersive experience in an alternate reality. This is facilitated by technologies such as Head-Mounted Displays (HMDs) and tracking systems. Such immersion permits users to interact within the virtual environment, offering potential enhancements in the utilization of media in classrooms and increasing accessibility for a range of learners (Chen and Chen, 2022; Chang et al., 2023; Roberts-Yates and Silvera-Tawil, 2019; Williams et al., 2022).

Yet, the incorporation of VR in educational settings raises ethical and practical challenges, particularly regarding the potential exclusion of certain learners (Buzio, Chiesa, and Toppan, 2017; Schäfer et al., 2023; Zender et al., 2022). Addressing these issues necessitates that VRLA development be grounded in educational theory, with a specific focus on inclusive education, as this paper intends to discuss.

Inclusion can be viewed in two ways: a "narrow" interpretation focused on special education and a "broader" perspective that considers multiple forms of inequality (Rödel and Simon, 2022a). This paper follows the broader interpretation, identifying inclusion as a continuous process that ensures equal participation by removing barriers and promoting accessibility. This perspective emphasizes collaborative learning for all students, regardless of their backgrounds and abilities (Rödel and Simon, 2022b).

2. Research Objectives

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To support the inclusive application of VR in schools, it's essential to understand how VRLAs can cater to a diverse student body. This paper's objective is to provide insights and recommendations for designing VRLAs that meet the needs of a wide range of learners. This will be accomplished by analyzing research related to the inclusive design elements of VRLAs and formulating the preliminary Inclusion Guidelines for VR Learning (IGVRL) for developers and researchers. The central research question guiding this review is: How can VRLAs be effectively designed to accommodate the diverse learning styles and needs of students in order to facilitate inclusive education in schools?

3. Method

To incorporate diverse knowledge sources, including qualitative research, quantitative data, and grounded theory, the "best-fit" framework synthesis technique, developed by Carroll, Booth, and Cooper in 2011 and refined by Carroll et al. in 2013, was employed.

This method requires researchers to apply a predefined theoretical framework to literature review findings. The "best-fit" approach suggests using an existing framework or synthesizing multiple frameworks. In this study, the Universal Design for Learning (UDL) framework (CAST, 2018) was selected. Framework synthesis is effective for formulating guidelines for inclusive VRLAs, allowing the alignment of specific settings (e.g., VRLAs for K-12) with a fitting framework (e.g., inclusive education). Hence, it is frequently employed in guideline development (Flemming et al., 2019) and facilitates the merging of theory and practical findings (Booth and Carroll, 2015).

However, it's acknowledged that the "best-fit" approach's frameworks are not flawless (Cooke, Smith, and Booth, 2012). After aligning evidence with the predetermined framework, any unrepresented findings will be incorporated by adding new themes backed by evidence. The "best-fit" method is apt for this study as adopting a related framework aids in interpreting intricate data within a defined context (Brunton, Oliver, and Thomas, 2020). The steps of this method are illustrated in figure 1.

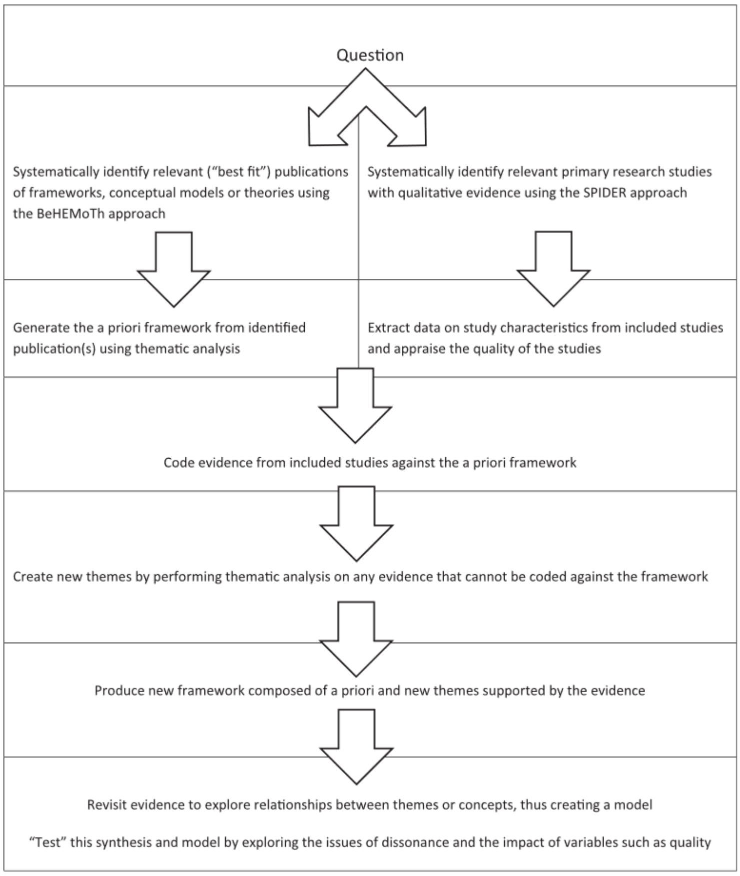

Figure 1: Best-Fit Framework Synthesis (Carroll et al., 2013)

3.1 The Universal Design for Learning Framework

The theory of UDL has roots in universal design principles from architecture, which incorporated features to make products universally accessible (Hickey, 2021). UDL emerged from efforts to address learning barriers for students with specific disabilities, eventually broadening its scope to improve access for all students (Hickey, 2021).

UDL is a framework that guides the creation of adaptive learning experiences to cater to all learners. It emphasizes diverse methods of expression, representation, and engagement, rather than a uniform solution (Meyer, Rose, and Gordon, 2014; CAST, 2018). Though not reliant on technology, UDL presents a pedagogical perspective that examines the potential benefits of technology in meeting varied learning needs (Bray et al., 2023).

Incorporating inclusive design from the onset in e-Learning tool development ensures considerations of accessibility and diverse learner engagement early in the design process (Patzer and Pinkwart, 2017; Morra and Reynolds, 2010).

The relevance of UDL to designing inclusive VRLAs lies in its understanding that accessibility and inclusive education are intertwined. There's existing literature on applying UDL in e-Learning, technology-enhanced learning, and assistive technologies (Morra and Reynolds, 2010; Cunningham and Murphy, 2018; Courtad, 2019; Poore-Pariseau, 2010; Al-Azawei, Parslow, and Lundqvist, 2017).

UDL was chosen over other models of inclusive education for its particular focus on learning content design. The framework Index for Inclusion (Booth and Ainscow, 2011) was not selected because of its focus on broader school culture, leading to categories of very low relevance to this research. Another possible model would have been the Didactic Model for Inclusive Teaching and Learning (Frohn, 2022). This model was not chosen because only 4 of its categories would have been applicable and that would have led to a lack of differentiation for this analysis.

3.2 UDL Coding Framework

The UDL guidelines, developed and published by the Center for Applied Special Technology (CAST, 2018), will serve as the foundation for the framework analysis. An overview of the framework is depicted in Figure 2.

Figure 2: UDL Guidelines (CAST, 2018)

This framework will be used to organize information extracted from the literature search into the nine categories, along with a tenth category for inclusion-related points not covered by UDL, if necessary. During the analysis, the mapped information, such as best practices, case study insights, quantitative and qualitative data, as well as pre-existing guidelines, will be synthesized into a set of guidelines for the development of inclusive VRLAs.

3.3 Systemic Review

Having the framework in advance influenced the decisions regarding how the literature search will be conducted. The chosen review strategy is a systematic review following the SPIDER search strategy (Cooke, Smith, and Booth, 2012).

3.3.1 Search strategy

An acknowledged search strategy was employed to retrieve relevant articles for qualitative and mixed-method research. The SPIDER search strategy was adopted to address ambiguities in titles and abstracts of potential articles (Cooke, Smith, and Booth, 2012). SPIDER was used to pinpoint relevant research, with search terms detailed in Table 1, adapted for each database's syntax. The focus was on K-12 education, encompassing educational processes, including inclusion, accessibility, and VR.

Table 1: SPIDER search strategy

SPIDER Tool	Search Terms
S – Sample	school OR k-12 OR k12 OR classroom
PI – Phenomenon of Interest	"education OR learning OR teaching OR curriculum AND inclusi* OR accessib* OR disab* OR UDL OR "universal design" OR divers* AND "virtual reality" OR VR OR virtual-reality
D – Design	questionnaire* OR survey* OR interview OR "focus group" OR case-stud* OR "case study" OR "case-studies" OR observ* OR experiment* OR stud* OR meta-analysis OR ethnography OR "meta analysis" OR "grounded theory" OR inquir* OR analy*
E – Evaluation	view* OR experienc* OR opinion* OR attitude* OR perce* OR belief* OR feel* OR know* OR understand* OR outcome* OR characteristic* OR impact* OR insight* OR learn* OR trend* OR pattern*
R – Research Type	qualitative OR mixed-method OR "mixed method" OR quantitative
[S AND PI] AND [(D OR E) AND R]	

Criteria for design, evaluation, and research type drew from terms in pertinent research papers, with keyword searches restricted to titles and abstracts. Only articles published post-2012 were included, coinciding with a resurgence of interest in Virtual Reality and the evolution of consumer head mounted displays. The term "learning applications" was excluded to ensure a broad dataset scope.

Given the interdisciplinary nature of e-learning and educational technologies, especially concerning inclusion, a diverse database set was chosen. The Association for Computing Machinery Guide to Computing Literature covered computing sciences, Scopus offered a broader coverage, ERIC represented educational sciences, and Taylor & Francis added more interdisciplinary papers. More databases, such as Google Scholar, were not used to limit the number of false positives and to stick to peer-reviewed studies. The selection of databases from a varied set of disciplines ensures a sufficient breadth of focus. Table 2 presents the records identified per database.

Table 2: Query results by database

Data Source	Results
ACM Guide to Computing Literature Date: 17th of August 2023	239
SCOPUS Date: 17th of August 2023	44
ERIC Date: 17th of August 2023 (Does not support the use of wildcard * Manual adjustments to the query were made)	15
Taylor & Francis Date: 17th of August 2023 (Does not support the use of wildcard * Manual adjustments to the query were made)	10
Total	308

3.3.2 *Initial screening and exclusion criteria*

From an initial count of 283 records, 13 duplicates and 12 conference reviews were removed. The remaining records were screened by title and abstract using the following exclusion criteria:

- Records unrelated to VR, e.g., those emphasizing serious games, virtual worlds, 2D-based virtual learning, or augmented reality.
- Studies where VR had only a peripheral role.
- Records not set in a K-12 environment, like higher education studies or those outside a school context.
- Records not in English or German.
- Research centered on teacher education rather than K-12 student VR use.

After applying these criteria, 15 records remained. Inclusivity in education was not an explicit screening criterion at this stage, as it was challenging to identify from abstracts alone. The subsequent framework analysis will emphasize inclusive education.

3.3.3 *Backwards snowballing*

To complement the initial search strategy and address the limited number of records, a backward snowballing technique (Wohlin, 2014) was used. From the initial 15 records, relevant references were extracted based on titles, then expanded by reviewing the introduction and background sections for citations. New references were checked for duplicates, assessed for publication date (after 2012), and screened using the prior exclusion criteria.

This approach added 24 more records, suggesting that the initial search might have missed some pertinent studies, possibly due to the specific inclusion-related terms in the SPIDER search. Insights about inclusive education can sometimes be located within broader educational findings. Using the snowballing technique effectively compensated for this limitation, bringing the total to 39 records for further analysis.

3.3.4 *Full-text eligibility*

Each identified record was examined in full to ensure its relevance beyond the title and abstract, leading to the exclusion of 21 records. Some did not meet the defined "virtual-reality" criteria, focusing on aspects like stereoscopic 3D or 2D virtual worlds. Others lacked insights pertinent to creating inclusive VRLA design guidelines, often concentrating solely on the efficacy of VR interventions without discussing application design details. Also, studies with recommendations specific to a narrow context, like language learning applications (e.g., Parmaxi, 2023), were excluded. Ultimately, 18 papers were selected for the final analysis. A summary of this process is depicted in Figure 3.

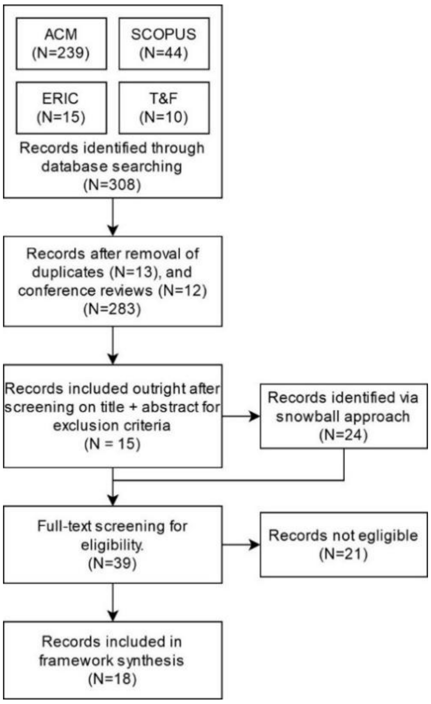

Figure 3: Flowchart of the literature search process

4. Results: The Preliminary Inclusion Guidelines for VR Learning (IGVRL)

The review's coding focused on identifying design recommendations associated with positive effects on inclusive learning, omitting broader inquiries on VR's general value in inclusive education. For example, "Increased motivation in students with learning disabilities" (Papanastasiou et al., 2019) was not included, as it didn't tie to a specific design decision. The synthesis centered on recommendations like "Expanding interaction modes to enhance embodied learning" (Thompson et al., 2018). While some observations, such as VR's capability to simulate multiple media channels (Thompson et al., 2018), may seem broad, they align with suggestions emphasizing the importance of experience fidelity and multimedia elements in VRLAs. This paper first offers tables (Tables 3-11) showing raw results based on UDL's 9 categories, then refines them into guidelines. Some findings are applicable to multiple categories but aren't repetitively listed.

4.1 Provide Options for Recruiting Interest

Table 3: Raw results for (1)

Thompson et al., 2018	• Allow learners to be an active explorer rather than a passive observer;
Cheng and Tsai, 2019	• Presence is positively linked to motivation; • Presence is linked to self-efficacy; • Task-based learning approach should be integrated to promote autonomous learning;
Chua et al., 2019	• Interactivity with VR content generates better engagement, enjoyment and potentially performance;
Papanastasiou et al., 2019	• VR allows learners to interact with virtual objects at their own pace and learn through a constructivist approach, encouraging active participation rather than passivity; • Provide realistic and interactive role-playing situations;
Yang et al., 2020	• Achieving authenticity through realistic graphic design;
Bodzin et al., 2021	• Support engagement to increase positive motivational influences on learning; • Incorporate students proactive behavior into instructions by for example including choices for the user to take that influences their learning path; • Make tasks authentic in order to promote engagement; • Incorporate narrative in learning applications to promote interest;

A dominant theme identified is the emphasis on active, autonomous, and constructivist learning scenarios (Thompson et al., 2018; Cheng and Tsai, 2019; Chua et al., 2019; Papanastasiou et al., 2019; Bodzin et al., 2021). This correlates with the UDL principle "Optimize individual choice and autonomy" (CAST, 2018). These scenarios position learners as proactive, allowing considerable autonomous individualization. The literature indicates that such scenarios prioritize active exploration, task-based learning, and high interactivity with virtual worlds.

Another notable theme is the significance of presence in boosting motivation and engagement (Cheng and Tsai, 2019; Yang et al., 2020; Bodzin et al., 2021). This corresponds with UDL's "Optimize relevance, value, and authenticity" (CAST, 2018). The literature suggests achieving this through realism in graphics and simulations, linking VR to students' real-world experiences, and integrating narratives or role-play elements (Papanastasiou et al., 2019; Bodzin et al., 2021).

The third theme, categorized by CAST as "Minimize threats and distractions" (2018), didn't provide distinct VRLAs development guidelines. The literature reiterated VR's safety compared to real environments (Fransson, Holmberg, and Westelius, 2020; Roberts-Yates and Silvera-Tawil, 2019; Papanastasiou et al., 2019), which seems more content-specific than a design guideline. More studies on VR learning and cognitive load might offer clarity.

Synthesized guidelines:

- Advocate for active exploration and problem-solving in VR, aligning with constructivist learning methods.
- Incorporate interactive elements, enabling learners to engage with the virtual environment.
- Embrace task-based learning within VR, allowing learner agency.
- Provide opportunities for choices and decisions, endorsing learner autonomy.
- Boost presence by connecting VR to meaningful real-world or engaging narratives.

- Prioritize authenticity through realistic graphics and immersive technology.

4.2 Provide Options for Perception

Table 4: Raw results for (2)

Thompson et al., 2018	• Utilize 3D visualizations for subject specific content; • Design with spatial awareness and spatial presence;
Hamilton et al., 2021	• Design with spatial understanding and Spatial visualization;
Cheng and Tsai, 2019	• Spatial presence highly related to attitudes towards learning activity;
Ritter, Stone and Chambers, 2019	• Use a mix of 360° Photos, video and 3D-modelled; • Blend (photorealistic) 3d-Models with 360° photos and videos;
Yang et al., 2020	• Supplying captions is an effective way to boost listening and reading comprehension;
Bodzin et al., 2021	• Include a wide variety of media, such as authentic imagery, text, data displays, animations, video content, audio narration; • Use multiple and varied representations to promote deeper understandings and sense-making of concepts;
Georgiou, Tsivitanidou and Ioannou, 2021	• Utilize external projection, e.g., the classroom being able to see what the VR user is doing;
Holly et al., 2021	• Ensure high levels of immersion; • User interface should be tailored to the VR world (integrated into the VR world);

A primary theme suggests VR's strength as a multimedia tool capable of offering diverse content (Thompson et al., 2018; Yang et al., 2020; Hamilton et al., 2021; Ritter, Stone, and Chambers, 2019; Bodzin et al., 2021). This corresponds with UDL's guidelines to present alternatives for auditory and visual information (CAST, 2018). Spatial understanding and awareness are underscored, being unique to immersive media (Thompson et al., 2018; Hamilton et al., 2021; Cheng and Tsai, 2019).

The literature review revealed a gap in addressing the UDL guideline "Offer ways of customizing the display of information" (CAST, 2018). Given VR's software-driven nature, opportunities exist for features like color-blind modes and audio descriptions. Further research into VRLA customization is needed.

Two supplementary themes were noted. First, the VR application UI should be directly interactive and embedded within the environment (Holly et al., 2021), enhancing immersion. Second, external projection techniques, like beamers or tablets, can make the VR experience accessible to wider audiences (Georgiou, Tsivitanidou, and Ioannou, 2021). These themes weren't directly linked to UDL guidelines but were briefly associated with perception.

Synthesized guidelines:

- Provide diverse content modalities, encompassing various media forms, 3D visualizations, 360° visuals, 3D models, and audio narratives. Aim for seamless integration of 360° content with 3D models.
- Enhance spatial awareness with interactive environments emphasizing exploration and physical navigation, including VR-integrated UI elements.
- Utilize external projection methods, allowing the larger group to view VR experiences.
- Introduce customization options addressing audio-visual and spatial components.
- Ensure the inclusion of closed captions for auditory content.

4.3 Provide Options for Physical Action

Table 5: Raw results for (3)

Thompson et al., 2018	• Create interactive and manipulatable simulation environments; • More modes of interaction enable higher embodied learning;
Cheng and Tsai, 2019	• Virtual Field trips can reduce barriers;
Papanastasiou et al., 2019	• Glove-based haptic interfaces allow for non-verbal communication;
Ritter, Stone and Chambers, 2019	• Use teleportation instead of controller-based walking to mitigate perceived motion sickness;
Fransson, Holmberg and Westelius, 2020	• Use sight, hearing and touch for interactions;
Yang et al., 2020	• Provide various modes of being able to navigate through and interact with objects in the environment;
Bodzin et al., 2021	• Provide access to locations not accessible for students with disabilities;

The UDL theme "Vary the methods for response and navigation" (CAST, 2018) underscores the value of multi-sensory interactive environments, emphasizing the integration of sight, hearing, and touch (Thompson et al., 2018; Papanastasiou et al., 2019; Fransson, Holmberg, and Westelius, 2020; Yang et al., 2020). To prevent motion sickness, varied navigation methods are essential (Ritter, Stone, and Chambers, 2019). Moreover, diversified controls can enhance embodied learning (Thompson et al., 2018) and cater to students with disabilities.

The UDL guideline "optimize access to tools and assistive technologies" (CAST, 2018) wasn't specifically addressed by the authors concerning VR tools for disabled students. Yet, VR was recognized as an assistive technology, granting experiences otherwise inaccessible to students with disabilities (Bodzin et al., 2021; Cheng and Tsai, 2019). The design emphasis shifts to how VR makes experiences accessible rather than VR's intrinsic accessibility.

Synthesized guidelines:

- Utilize diverse interaction modalities, including speech, gaze controls, haptic feedback, and controller inputs, facilitating a multi-sensory environment.
- Introduce alternative navigation options, like teleportation, to counteract motion sickness.
- Design VR environments that render experiences accessible to students with disabilities, such as virtual excursions to non-accessible sites.
- Integrate or enable compatibility with assistive technologies to ensure broad accessibility within the VR learning platform.

4.4 Provide Options for Effort and Persistence

Table 6: Raw results for (4)

Thompson et al., 2018	• Technology-enabled forms of collaboration and communication; • Ongoing feedback to the learners integrated into the application; • Allow learners to be an active explorer rather than a passive observer; • Collaborative work faciliates peer-learning by way of clear role division and asymmetrical tasks;
Papanastasiou et al., 2019	• Promote flexible, open and collaborative learning; • Provide realistic and interactive role-playing situations; • VR allows learners to interact with virtual objects at their own pace and learn through a constructivist approach, encouraging active participation rather than passivity;
Ritter, Stone and Chambers, 2019	• Embed feedback mechanisms, such as voice-over, in the design of the learning environment;

Southgate et al., 2019	• Networked IVR produces collaboration and deepens learning;
Fransson, Holmberg and Westelius, 2020	• In order for teachers to integrate different levels of challenge, they need to be able to produce and edit content for the VR application;
Yang et al., 2020	• Implement task-based assignments for students; • Achieving authenticity through realistic graphic design;
Bodzin et al., 2021	• Incorporate students proactive behaviour into instructions by for example including choices for the user to take that influences their learning path; • Implement Rapid feedback systems; • Tasks should strike the right challenge-skill balance; • Make tasks authentic in order to promote engagement;

The UDL guidelines delineate four themes for effort and persistence. The first, "heighten salience of goals and objectives" (CAST, 2018), suggests emphasizing goals in VR learning through graphic design or realism for engagement (Papanastasiou et al., 2019; Yang et al., 2020; Bodzin et al., 2021).

The second theme, “Vary demands and resources to optimize challenge” (CAST, 2018), emphasizes flexible tasks, self-guided learning, and proactive behaviors (Thompson et al., 2018; Papanastasiou et al., 2019; Yang et al., 2020; Bodzin et al., 2021). There's an emphasis on teacher customization (Fransson, Holmberg, and Westelius, 2020; Bodzin et al., 2021), indicating the potential need for authoring tools for educators.

The third theme, “foster collaboration and community” (CAST, 2018), is addressed by authors discussing VR's capability for collaboration (Thompson et al., 2018; Papanastasiou et al., 2019). They propose networked VR for shared learning spaces (Ritter, Stone, and Chambers, 2019).

Lastly, "increase master-oriented feedback" (CAST, 2018) recommends automated feedback for learners, as discussed by various authors (Thompson et al., 2018; Ritter, Stone, and Chambers, 2019; Bodzin et al., 2021).

Synthesized guidelines:

- Emphasize goals through authentic narratives in learning experiences.
- Encourage flexible and proactive task exploration, allowing learners to dictate their learning path.
- Offer configuration tools for educators to customize learning application content, ensuring they are user-friendly.
- Design cooperative tasks for both VR and non-VR participants.
- Develop networked VR learning applications supporting multi-user cooperation.
- Integrate automated feedback systems for real-time learner insights.

4.5 Provide Options for Language and Symbols

Table 7: Raw results for (5)

Thompson et al., 2018	• Multi-media simulation to address multiple channels of media reception; • Learners are prompted to gesture during problem solving; • Non-verbal communication with peers;
Papanastasiou et al., 2019	• Use avatars to enable students to develop social skills through communicating with avatars;
De Vasconcelos et al., 2020	• VR serious game for children with intellectual disabilities incorporated multiple means of representing language to improve literacy skills, such as: spoken instructions, written words, syllabic separation and pronounciation;
Fransson, Holmberg and Westelius, 2020	• Offer different languages instead of just English; • Avatars should have faces and the ability to gesture;

In the context of UDL guidelines for language and symbols, the findings align with two out of five categories, with the remaining three being context-dependent and not necessarily relying on the implementation of features or design considerations for VRLAs. “Clarify vocabulary and symbols,” “clarify syntax and structure,” and “support decoding of text, mathematical notation, and symbols” (CAST, 2018) were not explicitly addressed by the reviewed literature, thus implying a need for these to be researched further for suitability in VR.

The first theme addressed is “Illustrate through multiple media” (CAST, 2018). Beyond multimedia usage, there's discussion on the importance of accommodating diverse learner needs and learning styles through varied media and representation of language (Thompson et al., 2018; De Vasconcelos et al., 2020). The second theme, “promote understanding across languages” (CAST, 2018), indicated a need for multiple language options and emphasized non-verbal communication in VR through gestures and avatars (Thompson et al., 2018; Papanastasiou et al., 2019; Fransson, Holmberg, and Westelius, 2020).

Synthesized Guidelines:

- Offer optional linguistic aids for both text and spoken words within applications.
- Employ varied media to cater to diverse learner receptivity and provide alternative means for language reception.
- Ensure application availability in multiple languages.
- Develop avatars capable of emoting and using body language and gestures.

4.6 Provide Options for Expression and Communication

Table 8: Raw results for (6)

Thompson et al., 2018	• Learners are prompted to gesture during problem solving; • Non-verbal communication with peers;
Papanastasiou et al., 2019	• Use avatars to enable students to develop social skills through communicating with avatars;
Vishwanath et al., 2019	• Using VR for content-creation as a means of expression;
Fransson, Holmberg and Westelius, 2020	• Avatars should have faces and the ability to gesture;
Yang et al., 2020	• The virtual body should be similar in appearance or functionality to the individuals own body;

Expression and communication encompass three themes, with two identified in the literature review. "Use multiple media for communication" (CAST, 2018) relates to student communication methods during learning, primarily in VR via body language, gestures, avatars, and physical interactions, offering non-verbal alternatives to verbal communication (Thompson et al., 2018; Papanastasiou et al., 2019; Fransson, Holmberg, and Westelius, 2020; Yang et al., 2020). While avatars have been addressed in prior guidelines, potential undiscovered communication methods suggest the need for further research on non-verbal communication in VR.

The next theme, “use multiple tools for construction and composition” (CAST, 2018), is mentioned with reference to students creating content like 360° videos (Vishwanath et al., 2019). However, the emphasis on student-generated content was limited in the reviewed records, indicating the need for further research into user-generated content in VRLAs for more comprehensive guidelines. The last theme, “build fluencies with graduated levels of support for practice and performance” (CAST, 2018), was not addressed and should be a subject for future studies regarding scaffolding with VRLAs.

Synthesized Guidelines:

- For networked VR applications, incorporate network voice communication.
- Enable avatars with expressive faces to enhance communication and consider incorporating non-verbal communication methods.
- Allow students to create or import content into learning applications where appropriate.

4.7 Provide Options for Self Regulation

Table 9: Raw results for (7)

Thompson et al., 2018	• Creative positive interdependence in collaborative applications as a means for learners to reflect their contributions; • Clear rules & roles to optimize joint and individual effort;
Roberts-Yates and Silvera-Tawil, 2019	• Experiential learning to facilitate imagination, creative thinking, emotion activation, reflection;
Yang et al., 2020	• Observing classmates performance in VR application enables self-assessment;
Luo et al., 2021	• Consider automated assessment options within the application;

The UDL Guidelines for self-regulation include three themes, but only one was extensively addressed in the literature: "Develop self-assessment and reflection" (CAST, 2018). The other two themes, "Promote expectations and beliefs that optimize motivation" and "facilitate personal coping skills and strategies" (CAST, 2018), were briefly discussed by Thompson et al., who highlighted the significance of clear role distributions in optimizing VR learning engagement (2018). Although motivation and certain benefits, such as fostering confidence and reducing test anxiety, were discussed (Cheng and Tsai, 2019; Roberts-Yates and Silvera-Tawil, 2019), no direct ties to specific VRLA design choices were identified. Research to connect VRLA design features to student attitudes and self-perceptions is recommended for future exploration.

Regarding "Develop self-assessment and reflection", the literature suggests that observing peers in VR can encourage self-assessment and reflection (Thompson et al., 2018; Yang et al., 2020). Moreover, the experiential nature of learning promotes reflection (Roberts-Yates and Silvera-Tawil, 2019), and the potential for automated assessment in VRLAs has been suggested (Luo et al., 2021). The exact implementation of automated assessments requires consideration, emphasizing the need for further research. Some of these findings relate to previous guidelines, which will not be reiterated to avoid redundancy.

Synthesized guidelines:

- Assign clear roles or goals to guide learners, especially in multi-user VRLAs.
- Explore automatic assessment methods to provide learners with insights into their performance.

4.8 Provide Options for Comprehension

Table 10: Raw results for (8)

Thompson et al., 2018	• Authenticity of simulation allows for more well-rounded understanding of the subject;
Cheng and Tsai, 2019	• Heightened Sense of presence increases learning outcome;
Papanastasiou et al., 2019	• Transfer of emotional and social skills in VR applications to real situations;
Tilhou, Taylor and Crompton, 2020	• Connect to background knowledge by connecting contents of the VR application to ways of pre- or post- discussion in the classroom;
Bodzin et al., 2021	• Embed supports connecting learning content to prior experiences students have; • Provide supportive guidance in the form of advice, feedback, prompts and scaffolding to deepen learning; • Provide guided exploration or metacognitive support elements such as badges or points;
Holly et al., 2021	• Highlight the goal of the simulation before entering so the students dont feel lost in the simulation, for example through a pre-defined quest-list with clear task instructions;
Luo et al., 2021	• Consider adding scaffolding to the VR applications;

VRLAs can "activate or supply background knowledge" (CAST, 2018) through methods such as grounding the learning experiences in classroom discussions (Tilhou, Taylor, and Crompton, 2020) or by embedding supports that connect learning content to prior experiences within the VR (Bodzin et al., 2021).

To "highlight patterns, critical features, big ideas, and relationships" (CAST, 2018), it is vital to provide authentic VR experiences with a high degree of presence, as this leads to a more comprehensive understanding of the subject (Thompson et al., 2018; Cheng and Tsai, 2019). Clarifying the central goal or "big idea" of the simulation before beginning is another recommended method (Holly et al., 2021).

Regarding guiding "information processing and visualization" (CAST, 2018), the literature suggests incorporating guided exploration and scaffolding, such as metacognitive support elements like badges or points, and providing a pre-defined quest-list before entering the simulation (Bodzin et al., 2021; Holly et al., 2021; Luo et al., 2021). Additionally, delivering guidance, advice, feedback, and prompts within the learning application is crucial (Bodzin et al., 2021).

However, strategies to "maximize transfer and generalization" (CAST, 2018) are scarcely discussed. Although the transfer of emotional and social skills in VR to real situations is noted (Papanastasiou et al., 2019), it doesn't yield new guidelines beyond existing ones on social and cooperative aspects of VRLAs.

Synthesized guidelines:

- Develop authentic virtual environments for a comprehensive understanding of the subject.
- Integrate pre- and post-simulation activities within the application's design.
- Embed context that relates to learners' prior experiences, allowing modifications by teachers or aligning with standard curricula.
- Offer guidance, feedback, prompts, and scaffolding to aid exploration within virtual environments.
- Incorporate metacognitive elements like badges, markers, arrows, and highlighting.
- Clearly define the simulation's goal for students at its outset.

4.9 Provide Options for Executive Functions

Table 11: Raw results for (9)

Thompson et al., 2018	• Clear role division helps planning and strategy development;

The UDL guidelines for this section yielded limited findings in the literature review. One study highlighted cooperative learning in VRLAs, noting a clear division of roles facilitated "planning and strategy development" (Thompson et al., 2018; CAST, 2018). Other general observations include potential enhancements in working memory and attention for individuals with traumatic brain injuries through VR applications (Papanastasiou et al., 2019). Collaborative Virtual Environments supported communication among children with ASD (Papanastasiou et al., 2019). Additionally, a connection between presence and self-efficacy was identified (Cheng and Tsai, 2019). However, these findings don't specify VR features or design decisions. Comprehensive research on all UDL guidelines for executive function is warranted for more detailed insights.

5. Discussion

The literature review and subsequent framework synthesis have yielded preliminary guidelines for developing inclusive VRLAs (preliminary IGVRL) and highlighted future research avenues and gaps in Universal Design for Learning (UDL) within VR education. While the preliminary IGVRL offer insights for VRLA developers, they are not exhaustive. Some findings from the literature are not sufficiently addressed, and the methodology employed has inherent limitations, emphasizing the preliminary nature of these guidelines. More expansive evaluation and testing are required.

5.1 Unaddressed Findings and Themes

Embodied learning and presence (Thompson et al., 2018; Cheng and Tsai, 2019; Holly et al., 2021) is one significant theme not adequately encapsulated in the UDL. While it could be connected with multimedia usage or physical action, its distinctiveness in VR learning is not sufficiently recognized. These findings underscore the need for future research on inclusive embodied learning and how it relates to this set of guidelines.

The importance of cooperation and collaboration has been acknowledged (Thompson et al., 2018; Papanastasiou et al., 2019; Southgate et al., 2019), but its treatment within the framework is mainly under the banner of sustaining effort and persistence. Inclusive education literature often stresses cooperation's role in fostering inclusivity and enhancing social competencies. Thus, comprehensive research on VR cooperation and collaboration, including design and technological requirements for multi-user VR, is necessary.

Another recurring theme, not wholly represented in the guidelines, concerns the nature of VR content. Suggestions range from experiences fostering perspective-taking (Vishwanath et al., 2019; Hamilton et al., 2021) and cultural sensitivity (Brown et al., 2021) to exploratory applications anchored in instructional design and constructivism (Georgiou, Tsivitanidou and Ioannou, 2021). As critical as the method of VR application deployment is the content chosen. Therefore, analyzing VRLA types from an inclusive education standpoint is a relevant future research area.

Addressing VR accessibility features is essential. While some were mentioned within the framework's categories, a more in-depth exploration is needed. Existing guidelines focus on VR games (Heilemann, Zimmermann, and Münster, 2021), but they weren't within the scope of this synthesis. As accessibility underpins inclusive education, further research into VR accessibility guidelines is crucial.

Lastly, the UDL framework doesn't entirely encompass other core inclusive education concerns: anti-discrimination, gender equality, and cultural inclusion (Rödel and Simon, 2022b). Some authors broached these subjects (Vishwanath et al., 2019; Brown et al., 2021), indicating the need for a comprehensive review dedicated to these topics and subsequent guideline development.

5.2 Limitations

The review's primary limitation was its search strategy, which aimed to identify items with an explicitly inclusion-oriented focus. Yet, many results were false positives, with few papers explicitly discussing concepts related to inclusion. This suggests that the inclusion related keywords didn't provide sufficient value in filtering the results, while also enabling the possibility of missing relevant papers simply because they did not use explicitly inclusion theory related keywords. Backward snowballing was employed to mitigate this limitation, however it cannot be said that this resulted in a truly comprehensive list of results. Broader search terms and the utilization of more databases is advisable for future research.

The review's emphasis on school and K-12 settings was another limitation. Although the focus was VRLA design for schools, findings related to higher education outnumbered those from K-12. It's essential to explore how insights from higher education can inform K-12 VRLA design. Future research should consider diverse search strategies to address this gap, making findings from other educational contexts relevant for K-12.

Additionally, using the "best-fit" framework method for synthesizing findings meant that no quality assessment of the included studies was conducted (Carroll et al., 2013). Thus, the guidelines should be viewed as preliminary insights rather than definitive recommendations. Future research should aim to enhance, evaluate, and validate these guidelines to ensure their validity and reliability.

6. Conclusion and Future Research

Using the "best-fit" framework synthesis method based on the UDL framework, initial guidelines for inclusive VRLAs in K-12 settings were identified. This set is called preliminary IGVRL. These guidelines serve as a starting point for further research and the development of VRLAs in study settings. Instead of offering a complete set of guidelines, this review marks the beginning of an extended research endeavor, presenting foundational categories from the literature and highlighting various research gaps to be addressed. The preliminary IGVRL represent a first answer to the question of how to effectively design VRLAs to accommodate diverse learning styles and needs of students in order to facilitate inclusive education in schools. Future research should focus on refining research questions to explore the design, cognitive aspects, and inclusive features of VR learning applications. Identified topics include investigating the impact of audio-visual customization, locomotion-systems, assistive technologies, non-verbal communications, user-generated content, scaffolding, and automated assessment on student attitudes and self-perception. Additionally, there is a need for research on metacognitive support elements, learning transfer, executive function, inclusive embodied learning, collaboration guidelines, and an analysis of genres and types of VR learning applications, particularly with an emphasis on accessibility.

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