What is Your VR Use Case for Educational Like: A State-Of-The-Art Taxonomy

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Abstract: Virtual reality has emerged as an influential technology in the educational landscape, offering learners and teachers immersive and interactive experiences that enhance traditional teaching methods. However, despite the increasing importance of virtual reality in education, a systematic description and classification of virtual reality use cases in education is still lacking. This limits the understanding and comparability of virtual reality use cases and highlights the need for a structured approach. This study asks the research question: How can virtual reality educational use cases, identified in the literature, be described, and classified? To classify these use cases, this study develops a state-of-the-art taxonomy. The taxonomy was developed in a combination of a conceptual-to-empirical and empirical-to-conceptual approach. The first stage to develop the taxonomy was based on a conceptual-to-empirical approach. Here, the concepts of virtual reality, use case and education serve as meta-characteristics and theoretical structure. To further detail the dimensions and characteristics, a systematic literature review was conducted by following a PRISMA-guided search and selection process. Therefore, the scientific databases Science Direct, AISel and Springer Link were used to search for studies between 2018 and 2023, obtaining a sample of 39 publications. As the conceptual-to-empirical approach did not richly describe the analysed virtual reality use cases from the studies, additional dimensions and characteristics were identified inductively. Therefore, a second iteration was conducted relating to the empirical-to-conceptual approach. This process explored the practical aspects of virtual reality scenarios and added applicable and practical characteristics to the initial theoretical foundation. The result is a comprehensive taxonomy of virtual reality use cases in education that contributes significantly to existing knowledge and provides a solid foundation for future research. The final taxonomy includes 17 dimensions and 37 characteristics. These findings can support educators to understand the nature of virtual reality use cases, enabling them to describe and implement such use cases effectively within educational settings.

Keywords: Virtual reality, Use cases, Education, Taxonomy, Systematic literature review

1. Introduction

Virtual Reality (VR) is an emerging technology that impacts different sectors, including education (Marks and Thomas, 2022). VR disrupts traditional educational scenarios by immersing students in interactive, three-dimensional environments (Alfalah, 2018). The immersive nature of VR opens up unique opportunities for delivering educational content, ranging from virtual field trips to complex scientific simulations. These unique opportunities are increasingly recognized by researchers (e.g., the call for papers for the Special Issue on Extended Realities for Learning from the Electronic Journal of e-Learning (EJEL)), educators (Dai, Garcia and Olave-Encina, 2023; Marks and Thomas, 2022; Sherman and Craig, 2019), and policymakers (European Commission, 2023). Thus, VR's mass-market adoption has expanded the range of its learning scenarios over the past decade (Alsop, 2023). However, despite the increased recognition and application of VR in education, there is still a lack of systematic description and classification of educational VR use cases. The need to define and study the main features emerging from VR characteristics is seen as a crucial step towards understanding the contribution of virtual environments to learning outcomes (Natsis, 2021). Educators have a strong interest in improving their understanding of VR (Gregory 2016), but the complexity of the task is increased by the evolving and often inconsistent VR terminology (Sherman, 2019). Identifying the unique characteristics of VR-supported learning environments is essential for a comprehensive investigation of its educational possibilities (Won et al., 2023). However, literature indicates significant inconsistencies between the understanding of the unique features of VR and its application in learning, hindering the understanding and comparability of VR use cases (Won et al., 2023). Furthermore, EJEL calls for contributions on theory building regarding the implementation of XR (VR and augmented reality)-based learning scenarios. To shed light on this descriptive confusion and contribute a structure to implement VR-based learning scenarios, this study asks the research question (RQ): *How can VR educational use cases, identified in the literature, be described, and classified?*

To answer the RQ, this study develops a state-of-the-art taxonomy of VR use cases in education, inspired by Radiantis' (2020) call to develop "a taxonomy of learning theories and other framing factors for educational VR

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applications" (Radianti et al., 2020, pp.22). Taxonomies structure the field of knowledge (Kundisch et al., 2022). To build up such a taxonomy, dimensions and specific characteristics of VR use cases are systematically structured and organized.

The remainder of this paper is structured as follows. To provide a solid conceptual foundation for the taxonomy development, the concepts of *VR*, *use case* and *education* are theorized in the next section. The aim is, to gain descriptive dimensions from these concepts by analysing educational VR use cases deductively. The third section introduces the research design. A systematic literature review (SLR) is conducted to synthesize the existing body of knowledge of VR, use cases and education. The taxonomy development adapts the methodology by Nickerson, Varshney and Muntermann (2013). Then, the taxonomy, its dimensions and characteristics are presented. The fifth section demonstrates the applicability of the taxonomy by classifying a real-world education use case, which serves as an illustrative scenario (cf. Szopinski, Schoormann and Kundisch, 2019). Finally, this study discusses its findings, outlines the implications, reflects on limitations, and proposes future research paths.

2. Theoretical Background

This study utilizes the triad of the concepts *VR*, *use case*, and *education*. Pivotal studies were analysed to identify dimensions, these concepts are comprised of. Pivotal studies are those works widely cited and offering substantial contributions to VR research (Heim, 1994; Mikropoulos and Natsis, 2011; Sherman and Craig, 2019; Steuer, 1992; Suh and Lee, 2005). Complementarily, definitions of current industry leaders (Apple, 2023; Meta, 2023) and a renowned research institute (Gartner Inc., 2023) were also considered to align academic and practical view. Following these studies, *VR* is conceptualized by four key dimensions: (1) *immersion*, (2) *3D environment*, (3) *sensory feedback*, and (4) *autonomy in interaction* (Figure 1).

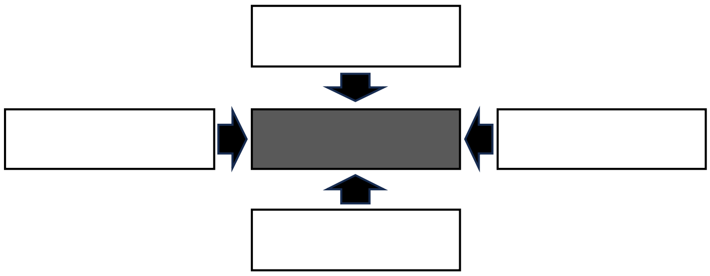

Figure 1: Dimensions of virtual reality

Immersion is the "perception of being physically present in a virtual world" (Sunday et al., 2022a, pp.2). It is either mentally or physically achieved (Sherman and Craig, 2019) by a headset immersing the senses into a virtual world (Meta, 2023). A virtual world is a digitally simulation of a real-world environment (Sherman and Craig, 2019). Recent studies refer to this virtual world as a computer-generated *3D environment* that immerses humans (Gartner Inc., 2023; Jiawei and Mokmin, 2023). *Sensory feedback* means the system's response to user input (Sherman and Craig, 2019), facilitated by e.g., touch-sensitive handheld controllers (Gartner Inc., 2023). *Interactivity* describes the users' ability to influence the virtual environment (Steuer, 1992), like manipulating virtual objects (Sherman and Craig, 2019). This influence implies a users' degree of autonomy, allowing learners to steer their own learning process within the virtual environment. Therefore, this study terms this dimension as the *autonomy in interaction*.

The concept *use case* comprises three key dimensions: (1) *trigger*, (2) *actors* and (3) *richness* (Figure 2).

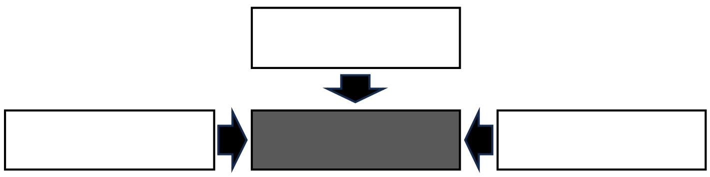

Figure 2: Dimensions of a use case

A *trigger* is a specific event that correlates with a system's behavior (Object Management Group, 2017; Weilkiens, 2007). Considering a VR use case as a holistic (black box) entity, a *trigger* is the motivator or underlying rationale behind the use case development, deviating from its standard definition. *Actors* refer to the various entities or individuals who interact with, influence, or are influenced by the use case (Balzert, 2011; Weilkiens, 2007). Scenarios are collections of goal-achieving interactions between the system and actors (Cockburn, 1999).

This study emphasizes the quantity of scenarios within a VR use case and coins the term *richness* (a virtual world with singular or multiple scenarios, Alfalah et al., 2019). Finally, the result of a use case is a predefined outcome of value (Weilkiens, 2007), which is not explicitly included in this study because all use cases are educational ones. Thus, results are covered more specifically by the concept *education*.

Four key dimensions conceptualize *education*: (1) *educational objectives*, (2) *aimed competencies*, (3) *autonomy in learning* and (4) *field of study* (Figure 3).

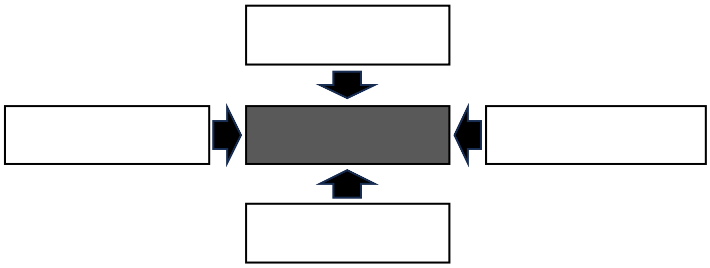

Figure 3: Dimensions of the concept education

Bloom's taxonomy of educational objectives, revised by Anderson and Krathwohl (2001), helps to classify *educational objectives* (Anderson and Krathwohl, 2001; Bloom, 1956). The artefact specifies six types of learning objectives: remember, understand, apply, analyse, evaluate, and create (Anderson and Krathwohl, 2001). While this taxonomy includes cognitive skills in detail, it excludes the emotional and psychomotor aspects that are essential to a comprehensive learning process. Therefore, the dimension *aimed competencies* incorporates cognitive, psychomotor, and social-emotional competencies. Cognitive competencies encompass intellectual skills and such processes that involve thought, understanding, and knowledge utilization. They span from simple information recall to complex tasks such as critical thinking, problem-solving, and the creation of new ideas (Anderson and Krathwohl, 2001). Psychomotor competencies refer to the acquisition and refinement of motor skills and physical movement, ranging from basic physical tasks to more complex, expressive actions that require precision, control, and highly developed motor skills (Harrow, 1972). Social-emotional competencies encompass emotional responses, social interactions, and the development of personal values. They range from receiving and responding to emotions, to understanding, accepting, and adopting various values and attitudes in social contexts (Krathwohl, Bloom and Masia, 1965).

Self-Determination Theory (SDT) helps to define the third dimension of the concept *education*. SDT is a macro level theory of human motivation and personality (Deci and Ryan, 2015). It brings forth the concept of self-determined learning, which refers to autonomously decided learning processes and strategies by learners, based on their individual needs, interests, and goals (Deci and Ryan, 2015). This is in contrast to externally imposed learning processes and strategies dictated by external agencies or systems, such as standardized testing or teacher-directed instruction (Felixbrod and O'Leary, 1973). To address the main motivator of learning, the term *autonomy in learning* is used to express the dichotomy of learning motivation from externally imposed to self-determined. Finally, *education* happens within a discipline or *field of study* (Statistisches Bundesamt (Destatis), 2021). Here the standard of the Federal Statistical Office of Germany is used, proposing eight classes: 1) humanities, 2) sports, 3) law, economic and social sciences, 4) mathematics and natural sciences, 5) human medicine and health science 6) agricultural, forestry and food sciences, veterinary medicine, 7) engineering sciences, and 8) arts and art sciences (Destatis, 2021).

3. Research Methods

This study follows two methodical approaches. To structure the field of knowledge about educational VR use cases, a SLR is conducted. The SLR is structured into use case identification, use case extraction, and data evaluation (Kitchenham, 2007; PRISMA, 2023; Webster and Watson, 2002). All process steps are described in the next section. Data evaluation is done deductively, based on the structure given by the concepts introduced in section 2. After discussing the results of the deductive approach within the author team and noticing the limited richness of the descriptive power, it was decided to complement these results using an inductive approach as well. Finally, the dimensions and characteristics were structured using a morphological box as visualization of the taxonomy (Szopinski, Kundisch and Schoormann, 2020). In this study, dimensions provide the descriptive pattern of the concepts of *VR*, *use case* and *education*, while characteristics are specific attributes of these dimensions (Nickerson, Varshney and Muntermann, 2013). Figure 4 provides an overview of the research methods and taxonomy development process.

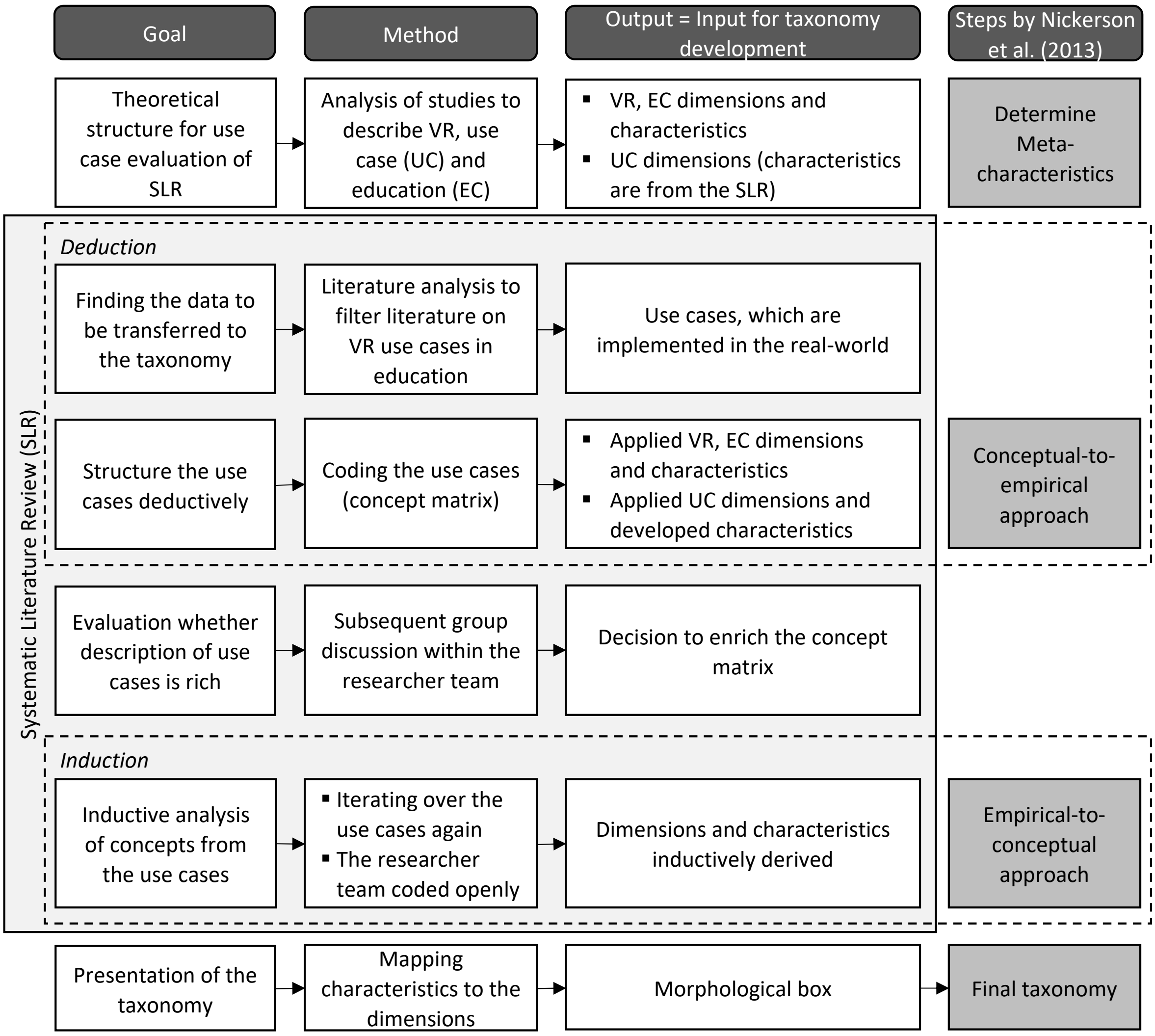

Figure 4: The taxonomy development process

3.1 Literature Review as Foundation for Taxonomy Development

To gather the use cases for taxonomy development, a SLR was conducted following Webster and Watson (2002). The PRISMA-guide was applied for the search and selection process of the publications (Figure 5). First, the search string was determined ("Virtual Reality" AND "Use Case") AND (learn, OR learning, OR teach, OR teaching). The search string was rather inclusive to gather a broad sample of literature and support the validity of the literature search process (vom Brocke et al., 2015). The scientific databases Science Direct, AISeL, and Springer Link with the publishing date between 2018 and 2023 were used. AISeL with its focus on Information Systems (IS) was selected because it highlights the significance of VR (Murphy, 2022). In contrast, Science Direct and Springer Link were expected to provide relevant literature on the use of VR in the education context due to their multidisciplinary coverage. 2018 was chosen due to the introduction of VR in the annually published Horizon Report, highlighting trends and developments in educational technologies for higher education (Becker et al., 2018). The next step selected papers based on boolean search results, applying inclusion and exclusion criteria to titles and abstracts.

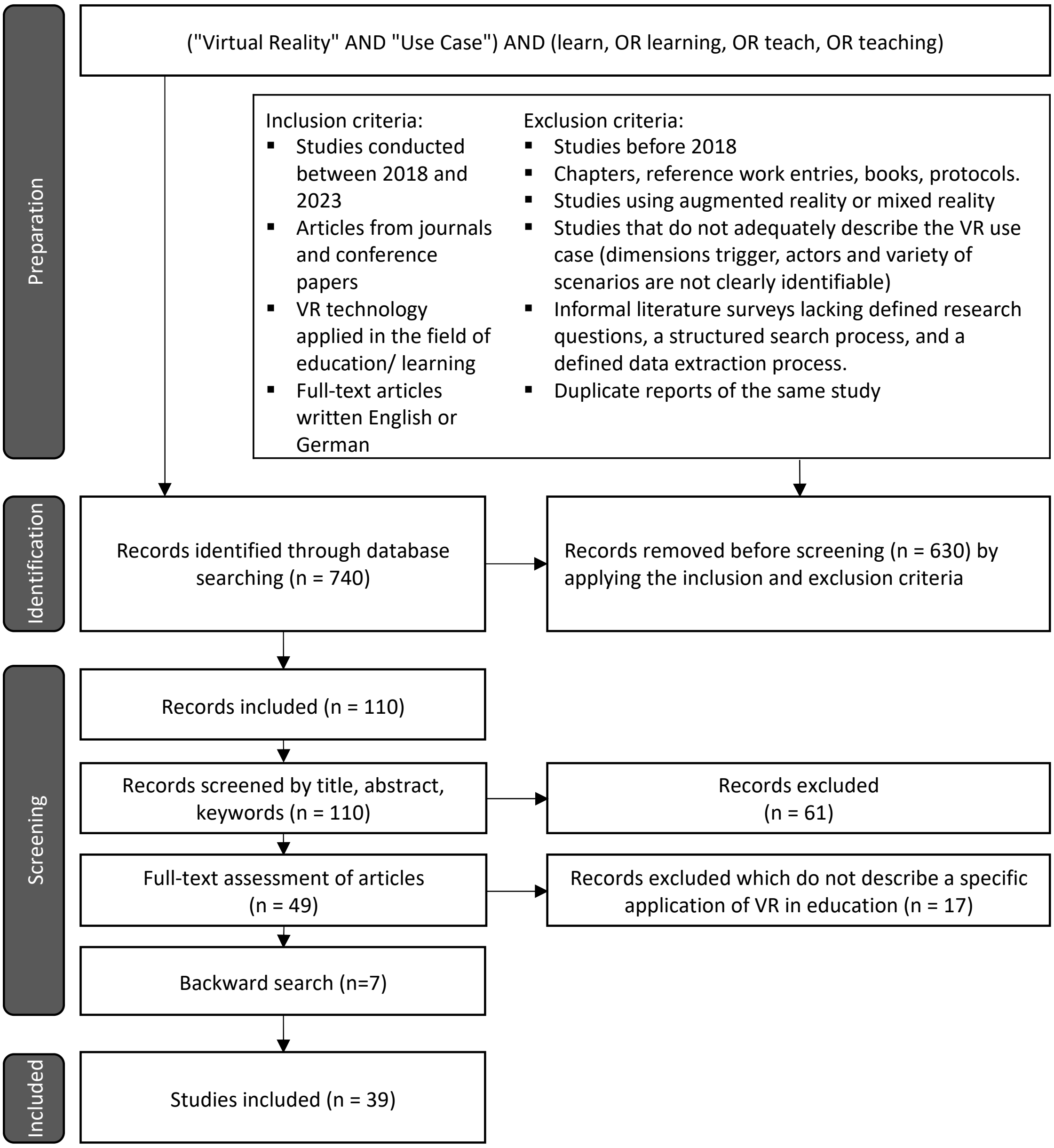

Figure 5: Flow chart for the search and selection process (cf. PRISMA, 2023)

The search was executed in May 2023, yielding 740 articles based on searches with the defined search term. After applying exclusion criteria 110 articles remained. Screening by title, abstract and keywords assessed 49 articles as being appropriate for a full-text review. Another 17 articles were excluded as they described VR in education generally rather than a specific use case. Backward search helped to identify seven further papers not covered by the searches. Finally, a total of 39 publications (30 journal, nine conference proceeding articles) were included in the analysis. Three of them were found in ScienceDirect, ten in AISeL and 26 in Springer Link. Then, the described use cases within the studies, were coded. For the coding process, the VR and education dimensions and characteristics were applied, as well as the use case dimensions.

3.2 Taxonomy Development Process

According to Nickerson, Varshney and Muntermann (2013), the target user groups, and the purpose of the taxonomy should be specified in the beginning of the taxonomy development process. The target user groups of the intended taxonomy are educators at the university level and VR use case designers, aiming to create future VR instantiations for education. The meta-characteristics of the process are the triad of concepts. These concepts shape the design of the dimensions determining the classes of the taxonomy. Last, ending conditions to evaluate the taxonomy are defined (Nickerson, Varshney and Muntermann, 2013). There are objective and subjective ending conditions. Objectively, the taxonomy should include all identified VR use cases in education, ensuring comprehensive coverage. Additionally, it should include the meta-characteristics that represent the main aspects of the VR use cases. By Nickerson, Varshney and Muntermann (2013) dimensions and characteristics have to be mutually exclusive and collectively exhaustive (MECE). This study deviates from this as some characteristics are not exclusive (e.g., an educational VR scenario can target the two educational characteristics "understand" and "apply"). Subjectively, the taxonomy should be concise, expandable, robust, explanatory, and comprehensive (Nickerson, Varshney and Muntermann, 2013). The fulfillment of these requirements is reflected after the taxonomy development in section 5 (Illustrative demonstration).

4. Conceptualization of Taxonomy Dimensions and Characteristics

Initially, the characteristics of *VR* and *education* dimensions are deductively identified. Then, the dimensions and characteristics of the concepts *VR* and *education* were applied for coding the publications selected in the search process of the SLR. The concept *use case* serves as an analogous term. Thus, the *use case* dimensions were applied to identify their characteristics by coding the use cases inductively.

4.1 Characteristics of the Virtual Reality Dimensions

Immersion is achieved through a combination of *vividness* – the richness of representation of a mediated environment (Steuer, 1992) – and *telepresence* – one's extent of one being present in that environment (Steuer, 1992). The degree of these characteristics differs for each use case. They are not MECE as both are pronounced to at least a low degree as both are characteristic for VR environments. For instance, high *vividness* with low *telepresence* denotes a scenario that is graphically rich and detailed but is not able to engage the user fully having active interaction with the environment. In contrast, high *telepresence* with low *vividness* occurs in a situation where the user feels a strong sense of presence and engagement, even if the visual details and richness (*vividness*) are comparatively low.

The characteristics of the dimension *3D environment* emerge from studies ranging from complex real-world scenarios (e.g., architecture replication) to simpler scenarios for visualizing 3D structures. A VR use case is either *realistic* or *abstract*. *Sensory feedback* can be detected by the five human senses (Sorabji, 1971). At present, *visual*, *auditory*, and *haptic* feedback are common in VR use cases and not mutually exclusive. Olfactory and gustatory feedback are non-existent. Visual feedback occurs in every use case. A virtual world is not possible without visual feedback (Sherman and Craig, 2019). However, *visual* is included as a characteristic as a use case can provide visual feedback by displaying texts and instructions. The degree of *autonomy in interaction* has two characteristics: *open* and *deterministic world*. An *open world* allows user-driven exploration, whereas a *deterministic world* confines users to pre-determined actions and outcomes. The characteristics of the VR dimensions are depicted by Table 1.

Table 1: Definition of the characteristics of the VR dimensions

Dim.	Characteristic	Definition	References
Immersion	Vividness	The degree of representational richness of the VR environment, defined by its formal features, meaning the depth and variety of sensory information the environment presents to the user. This could include high-resolution visuals, multi-sensory input, and full-body motion capture.	(Steuer, 1992)
	Telepresence	The degree to which a user feels present in the VR environment, rather than in their actual physical environment. It is the experience of being in a mediated environment through VR, often resulting in a lack of awareness of the actual physical surroundings.	
3D environment	Abstract environment	A simplified, imaginative scenario with limited objects and abstract representation, transcending the limitations of physical reality.	(Jiawei and Mokmin, 2023; Sherman and Craig, 2019; Sunday et al., 2022a)
	Realistic environment	A complex, real-world-like scenario with diverse interactions, aiming to mimic physical world phenomena.	
Sensory feedback	Visual	This involves the dynamic, real-time visual responses generated in the ' actions or movements.	(Sorabji, 1971)
	Auditory	Audio responses or sound effects are generated within the VR environment, enhancing the auditory perception of the virtual world.	
	Haptic	Tactile responses or vibrations are generated, typically via handheld controllers, enhancing the sense of touch and physical interaction within the VR environment.	

Dim.	Characteristic	Definition	References
Autonomy in interaction	Open world	It provides users with at least a moderate degree of autonomy. Users have the freedom to explore and interact with the environment at their will, but their actions do not significantly alter the VR environment's overall structure or narrative.	(Steuer, 1992)
	Deterministic world	It offers a lower degree of autonomy. The users' interactions are restricted to predetermined actions, and the outcomes are pre-established.	

4.2 Characteristics of the use Case Dimensions

The first dimension of the concept use case is *trigger*, encompassing three distinct characteristics: *representability*, *practicality*, and *ethical suitability* (definitions in Table 3). The *actors* in the scenarios are *educators*, *learners*, and *VR developers,* described in all use cases. A *learning facilitator* was described by four use cases. The *richness* is *single* or *multiple*. Especially in practical training, like surgical procedures, only one scenario is simulated and practiced. When replicating real-world scenarios, such as virtual laboratory environments, typically multiple scenarios are simulated.

Table 2 shows the definitions of these characteristics.

Table 2: Definition of the characteristics of the use case dimensions

Dim.	Characteristic	Definition	References
Trigger	Representability	’ x communicate complex educational concepts effectively. The ability is manifested in simplification (simplifying complex ideas), interactive engagement (increasing motivation through game-like interactions), and realistic scenarios (creating immersive, accurate simulations of real-world environments for user interaction).	(Ahram et al., 2021; Bucchiarone, 2022; Dixon et al., 2020; Murphy, 2022; Solmaz et al., 2023)
	Practicability	’ ability to provide feasible and efficient educational solutions by transcending traditional limitations of cost, time, location (learners are unbound by geographic and time constraints), and operational constraints (VR overcome physical limitations or constraints of the real world).	(Dixon et al., 2020; Hernández-de-Menéndez, Vallejo Guevara and Morales-Menendez, 2019; Loveridge, 2020; Murphy, 2022)
	Ethical suitability	’ ability to uphold and address ethical considerations within educational environments, ensuring a commitment to health and safety, accessibility, and inclusion.	(Alfalah et al., 2019; Bucchiarone, 2022; Dai, Garcia, Olave-Encina, 2023, 2023)
Actors	Educator	Refers to the individual or entity responsible for delivering the educational content and experiences within the VR environment.	(Mikropoulos and Natsis, 2011)
	Learner	Refers to the individual who engages with the VR experience to learn or acquire new knowledge or skills.	
	Learning facilitator	Refers to the individual or entity that assists or guides the learning process within the VR environment.	(Meng and Yeh, 2022)
	VR scenario developer	Refers to the individual or entity that designs and creates the VR environments, experiences, and scenarios for educational purposes.	(Sunday et al., 2022a)
Richness	Single scenario	Refers to a VR use case that involves only one specific, focused educational environment or situation.	(Stella et al., 2023)
	Multiple scenarios	Refers to a VR use case encompassing various educational environments or situations, providing a broader range of experiences or contexts.	(Meng and Yeh, 2022)

4.3 Characteristics of the Education Dimensions

Educational objectives and their characteristics align with Bloom’s taxonomy (Anderson and Krathwohl, 2001; Bloom, 1956). *Aimed competencies* are defined as *social-emotional*, *cognitive*, and *psychomotor* (Anderson and Krathwohl, 2001; Harrow, 1972; Krathwohl, Bloom and Masia, 1965). The *autonomy in learning* bases on SDT (Deci and Ryan, 2015) and externally imposed learning processes (Felixbrod and O’Leary, 1973). Finally, *field of study* bases on a German standard (Statistisches Bundesamt (Destatis), 2021). Table 3 provides the definitions of each of these characteristics.

Table 3: Definition of the characteristics of the education dimensions

Dim.	Characteristic	Definition	References
Educational objectives	Remember	The objective to retrieve relevant knowledge from long-term memory.	(Anderson and Krathwohl, 2001)
	Understand	The objective to have learners construct meaning from instructional messages, whether presented orally, written, or graphically.	
	Apply	The objective to use learned procedures effectively to perform exercises or solve problems.	
	Analyse	The objective to break down the material into its constituent parts, understand its interrelations, and grasp the overall structure or purpose of the subject of matter.	
	Evaluate	The objective to make judgments based on specified criteria and standards.	
	Create	The objective to assemble elements to create a coherent and functional whole or to reshape existing elements into new patterns or structures.	
Aimed competencies	Cognitive	Intellectual skills and processes involving thought, understanding, and knowledge utilization. This ranges from simple recall of information to complex tasks such as critical thinking, problem-solving, and the creation of new ideas.	(Anderson and Krathwohl, 2001)
	Psychomotor	Acquisition and refinement of motor skills and physical movement. This ranges from basic physical tasks to more complex, expressive actions that require precision, control, and highly developed motor skills.	(Harrow, 1972)
	Social-emotional	Area of learning involving emotional responses, social interactions, and development of personal values. This ranges from receiving and responding to emotions, to understanding, accepting, and adopting values and attitudes in social contexts.	(Krathwohl, Bloom and Masia, 1965)
Autonomy in learning	Externally imposed	Refers to the learning processes and strategies that are dictated by external authorities or systems, such as standardized tests, or teacher-led instructions.	(Felixbrod and O'L , 197)
	Self-determined	Refers to the learning processes and strategies that are autonomously decided by the learners, based on their individual needs, interests, and goals.	(Deci and Ryan, 2015; Felixbrod O'L , 197)
Field of study	Humanities (1)	Area of study in which human society and culture are examined, including fields such as languages, literature, philosophy, and history.	(Destatis, 2021)
	Sports (2)	Area of study focusing on physical activities, health, fitness, and sports sciences.	
	Law, economics and social sci. (3)	Area of study focusing on social systems and behaviour, including disciplines such as law, economics, sociology, and political sciences.	
	Mathematics, natural sci. (4)	Area of study that covers disciplines such as mathematics, physics, chemistry, biology, and earth sciences.	
	Human medicine/ health sci. (5)	Area of study focusing on the comprehensive understanding and application of medical knowledge, encompassing general human medicine, health sciences, specialized fields within dentistry.	
	Agricultural, forestry, nutr. sci., veterinary med. (6)	Area of study focusing on agriculture, forestry, nutrition, and animal health.	
	Engineering sci. (7)	Area of study focusing on the application of scientific and mathematical principles to design, maintain, and improve structures, machines, systems, and processes across various specific fields.	
	Art, art sci. (8)	Area of study focusing on the visual and performing arts, art history, and art theory.	

The VR use cases of the 39 studies analyzed can be classified using the dimensions and characteristics of the three concepts described. Notably, two of the eight *field of studies* ((2), (6)) are not covered by the use cases. This indicates either a potential gap in the application of VR in education or in the literature sample studied. The concept matrix (Figure 6) exemplifies the description of the use cases. In the leftmost column the 39 references are listed in abbreviated Harvard style, clustered by application context. Each column on the right side is headlined by a concept discussed. The concepts are arranged hierarchically: 1) theoretical concept (e.g., VR), 2) dimensions (e.g., immersion), 3) characteristics (e.g., vividness).

Vividness/ Telepresence: H = High, L = Low. Fields of study (1-8) are defined in Table 3.			Virtual reality									Use case							Education											
			Immersion		3D environment		Sensory feedback			Autonomy in interaction		Trigger			Actors		Richness		Educational objectives						Aimed competencies			Autonomy in learning		Field of study
ID	Autor	App.	Vividness	Telepresence	Abstract	Realistic	Visual	Auditory	Haptic	Open World	Deterministic world	Representability	Practicability	Ethical suitability	Educator, Learner, VR scenario developer	Learning facilitator	Single	Multiple	Remember	Understand	Apply	Analyze	Evaluate	Create	Social-emotional	Cognitive	Psychomotor	Externally imposed	Self-determined	
1	(Alfalah et al., 2019)	Complex 3D visualization (e.g., anatomy)	H	L	X		X			X		X		X	X	X		X	X	X						X		X	X	5
2	(Banerjee et al., 2023)		H	H		X	X			X		X		X	X		X		X	X						X		X		5
3	(Stella et al., 2023)		L	H	X		X				X	X			X		X		X	X						X			X	4
4	(Zhu and Du, 2022)		H	H		X	X			X		X	X		X			X		X		X		X		X		X		7
5	(Bucchiarone, 2022)	Immersive conceptual learning (e.g., gamified learning)	H	H		X	X	X		X		X	X		X	X	X				X	X				X	X	X		7
6	(Heinemann et al., 2023)		H	H	X		X			X	X	X	X		X		X				X	X		X		X		X	X	8
7	(Jiawei and Mokmin, 2023)		H	L		X	X	X		X		X	X	X	X		X			X						X			X	8
8	(Sunday et al., 2022a)		H	H	X		X			X		X	X		X			X		X	X					X			X	4
9	Sunday et al., 2022b)		H	H	X		X	X		X		X	X		X			X		X	X					X			X	4
10	(Zhang and Lin, 2021)		H	H		X	X		X	X		X	X		X			X	X	X				X		X	X		X	8
11	(Chan et al., 2021),	Real-world replication (e.g., destinations, virt. laborities)	H	L	X		X	X		X		X	X	X	X		X			X						X			X	8
12	(Dai et al., 2023)		H	H	X		X	X		X	X	X	X	X	X			X				X	X			X			X	8
13	(Hernández-de-Menéndez et al., 2019)		H	H		X	X				X	X		X	X			X		X	X					X	X		X	7
14	(Kumlu and Ozkul, 2021)		H	H		X	X	X		X			X		X			X		X					X	X			X	3
15	(Sharma and Arora, 2022)		H	H		X	X			X		X	X		X			X		X					X	X			X	3
16	(Checa et al., 2021)	Practical skills training (e.g., surgical skills, pilot training, robotic operations)	H	H	X		X	X				X	X		X		X		X	X	X					X			X	7
17	(Gan et al., 2023)		H	H		X	X		X		X		X	X	X		X		X	X	X					X	X	X		5
18	(Hight et al., 2022)		H	H		X	X		X		X	X	X	X	X		X		X	X	X					X	X	X		7
19	(Malpani et al., 2020),		H	H		X	X		X		X		X	X	X		X		X	X	X					X	X	X		5
20	(Neira et al., 2021)		H	H		X	X		X		X		X	X	X		X			X	X					X	X		X	5
21	(Qu and Zhang, 2022)		H	H		X	X				X		X		X		X			X	X					X	X	X		7
22	(Shao et al., 2020),		H	H		X	X				X	X			X		X		X	X	X	X				X	X	X		5
23	(Vassigh et al., 2022),		H	H		X	X		X		X		X	X	X	X	X		X	X	X	X				X	X	X		7
24	(Yu et al., 2022)		H	H		X	X			X			X	X	X	X	X		X	X	X					X	X	X		5

Vividness/Telepresence:
H = High,
L = Low.
Fields of study (1-8) are defined in Table 3.

			Virtual reality									Use case							Education											
			Immersion		3D environment		Sensory feedback			Autonomy in interaction		Trigger			Actors		Richness		Educational objectives						Aimed competencies			Autonomy in learning		Field of study
ID	Autor	App.	Vividness	Telepresence	Abstract	Realistic	Visual	Auditory	Haptic	Open World	Deterministic world	Representability	Practicability	Ethical suitability	Educator, Learner, VR scenario developer	Learning facilitator	Single	Multiple	Remember	Understand	Apply	Analyze	Evaluate	Create	Social-emotional	Cognitive	Psychomotor	Externally imposed	Self-determined	
25	(Dixon et al., 2020)	Safety training	H	H		X	X	X			X	X		X	X		X			X	X	X				X	X	X		5
26	(Stone et al., 2021)		H	H		X	X	X		X		X		X	X			X		X	X	X			X	X		X		7
27	(Halabi, 2020)	Environment design	H	H		X	X			X			X		X		X			X	X	X		X		X	X		X	7
28	(Solmaz et al., 2023)		H	H		X	X			X			X		X		X			X	X	X		X		X	X		X	7
29	(Han et al., 2021)	Medical examination training	H	H		X	X		X		X		X	X	X		X			X	X	X	X		X	X	X	X		5
30	(Neira-Tovar et al., 2022)		H	H		X	X		X	X			X	X	X			X		X	X	X	X		X	X	X	X		5
31	(Schuelke et al., 2022)		H	H		X	X	X	X		X		X	X	X			X		X	X	X	X			X	X	X		5
32	(Huang et al., 2023)	Language training	H	H		X	X	X		X			X		X			X		X	X	X	X		X	X		X		1
33	(Klimova, 2021)		H	H		X	X	X		X			X		X			X		X	X	X	X		X	X		X		1
34	(Loveridge, 2020)	Team coordination training	H	H		X	X	X		X			X	X	X			X		X	X	X	X	X		X	X		X	8
35	(Murphy, 2022)		H	H		X	X	X			X		X	X	X		X			X	X	X	X			X	X	X		7
36	(Netland and Hines, 2021)		H	H		X	X	X		X			X		X		X			X	X	X	X			X		X		3
37	(Meng and Yeh, 2022),	Social skills training	H	H		X	X	X			X		X	X	X		X			X	X				X	X		X		5
38	(Pandey and Vaughn, 2021)		H	H		X	X	X			X		X	X	X			X		X	X	X			X	X				5
39	(Xu et al., 2021)	Industrial process visualization	H	H		X	X	X	X		X	X	X		X		X			X	X	X				X	X	X		7

Figure 6: Concept matrix

4.4 Characteristics Inductively Derived

The papers analysed contain additional concepts with descriptive power, worth to integrate into the description. Therefore, the goal is to inductively derive further dimensions and characteristics from the studies. In doing so, the correspondence between the description and real-world implementations is increased, as all studies reflect real-world VR use cases (actually implemented). To extract and organize the dimensions and characteristics, an open coding process was performed. During this process, each researcher elaborated on the dimensions and characteristics separately. In subsequent group discussions, consensus was sought within the researcher team, considering the inductive process of labeling the dimensions and characteristics. This approach was chosen to increase the objectivity of the taxonomy development process. The following dimensions are part of the use case descriptions of the studies: *purpose*, *techniques*, *user interaction mode*, *interaction identity*, *interaction mechanisms*, and *environmental interactivity*.

Purpose: This dimension refers to the specific objectives or desired outcomes that guide the use of VR instead of other technical implementations. This dimension corresponds to VR's fundamental capability to provide immersive experiences. *Sensitivity*, as one characteristic of purpose, refers to VR applications aimed at creating deeply immersive experiences through multi-sensory engagement. *Imagination* highlights VR's role in unleashing creativity through the interactive manipulation of virtual spaces. *Interactivity* underscores the emphasis on user engagement within VR environments. Lastly, *exploration* describes the use of VR for experiential learning, allowing users to understand concepts through first-hand virtual experiences.

Techniques: This dimension reflects the array of methods VR is offering; e.g. simulating real-world events, providing immersive visualization, or constructing virtual models of physical environments. The characteristics are *simulation*, *immersive visualization*, and *virtual reconstruction*, reflecting VR's versatile capability to mimic real-world scenarios, present complex structures in a user-friendly, immersive manner, and recreate past or non-existent entities, respectively.

User interaction mode: The dimensions' characteristics are *multiuser* and *single user* scenarios. This underlines VR's versatility in accommodating multiple users interacting within one virtual world simultaneously, as well as individual users immersing in a solo virtual experience.

Interaction identity: This reflects the inherently interactive nature of VR and its ability to connect users with a diverse range of entities, e.g., *virtual objects* or *virtual* and *virtualized actors*.

Interaction mechanism: This dimension outlines the purpose of user interactions, that is *communication*, *cooperation*, or *coordination*.

Environmental interactivity: One of VR's defining features is its capacity to provide environments that users can manipulate at different levels. That can offer experiences such as *object manipulation*, *environment manipulation*, or *no manipulation* at all. Table 4 lists the definitions of the additional characteristics.

Table 4: Definition of the characteristics inductively derived

Dim.	Characteristic	Definition	References
Purpose	Sensitivity	Refers to VR applications that are designed to engage the user's senses, providing a deeply immersive experience. This could include VR experiences that incorporate not only visual and auditory stimuli but also tactile feedback.	(Chan, Bogdanovic, and Kalivarapu, 2021; Zhang and Lin, 2021)
	Imagination	VR applications intended to stimulate the user's creativity to modify real-life spaces.	(Halabi, 2020)
	Interactivity	VR applications intended to emphasize user interaction.	(Klimova, 2021)
	Exploration	VR applications designed for users to learn about different concepts by experiencing them.	(Hernández-de-Menéndez, Vallejo Guevara and Morales-Menendez, 2019)
Techniques	Simulation	A technique where VR is used to replicate real-world environments or situations (e.g., flight simulators for pilots, surgical practice for doctors).	(Gan et al., 2023; Hight et al., 2022)
	Immersive visualization	A technique where VR is used to visualize complex data or structures in a three-dimensional, immersive way (e.g., anatomy, crystal structures, architecture).	(Banerjee et al., 2023; Stella et al., 2023)

Dim.	Characteristic	Definition	References
	Virtual reconstruction	A technique where VR is used to recreate historical sites, or other entities that no longer exist (e.g., archaeology, history).	(Chan, Bogdanovic and Kalivarapu, 2021)
User interaction mode	Multiuser	Multiuser environments enable multiple individuals to enter and interact within a virtual world simultaneously.	(Neira, Castañeda and Torres, 2021; Pandey and Vaughn, 2021)
	Single user	In single-user scenarios, one person immerses themselves in a virtual world without directly interacting with other users.	
Interaction identity	Virtual objects	These are non-anthropomorphic elements in the virtual environment with which users can interact (e.g., tools, environmental features).	(Mikropoulos and Natsis, 2011)
	Virtual actors	These are computer-controlled, anthropomorphic entities in the virtual world that users can interact with.	(Zhang and Lin, 2021)
	Virtualized actors	These are virtual representations of real individuals within the virtual environment.	(Dai, Garcia and Olave-Encina, 2023)
Interaction mechanism	Communication	Refer to the exchange of information between users in the virtual environment, or between users and virtual entities.	(Mikropoulos and Natsis, 2011)
	Cooperation	Refer to users working together to achieve common goals within the virtual environment.	Bucchiarone, 2022)
	Coordination	Refers to managing dependencies between tasks performed by different users or entities within the virtual environment.	(Loveridge, 2020)
Environmental Interactivity	Object manipulation	Refers to the ability of users to interact with and change individual objects within the virtual environment.	(Yu et al., 2022)
	Environment manipulation	Refers to the ability of users to modify the overall virtual environment, not limited to individual objects.	(Checa, Miguel-Alonso and Bustillo, 2021)
	No manipulation	Refers to VR experiences where users cannot change the virtual environment or objects within it, focusing on observation or pre-defined interactions instead.	

The developed dimensions and characteristics are organized clearly in a morphological box (Szopinski, Kundisch and Schoormann, 2020) in Figure 7. This represents a possibility of describing the educational VR use cases.

Meta-Concept	Dimension	Characteristics							
Virtual reality	Immersion	Vividness	Telepresence						
	3D environment	Abstract environment	Realistic environment						
	Sensory feedback	Visual	Auditory	Haptic					
	Autonomy in interaction	Open world	Deterministic world						
Use Case	Trigger	Representability	Practicability	Ethical suitability					
	Actors	Educator	Learner	Learning facilitator	VR scenario developer				
	Richness	Single scenario	Multiple scenarios						
Education	Learning objectives	Remember	Understand	Apply	Analyze	Evaluate	Create		
	Aimed competencies	Social-emotional	Cognitive	Physical					
	Autonomy in learning	Externally imposed	Self-determined						
	Field of study	Human-ities	Sports	Law, econ. and social sci.	Math., natural sci.	Human medicine/ health sci.	Agric., forestry & nutrition sci., veterinary medicine	Engin-eering sci.	Art, art sci.
Modalities	Purpose	Sensitivity	Imagination	Interactivity	Exploration				
	Techniques	Simulation	Immersive visualization	Virtual reconstruction					
	User interaction mode	Multiuser	Single user						
	Interaction identity	Virtual objects	Virtual actors	Virtualized actors					
	Interaction mechanisms	Communication	Cooperation	Coordination					
	Environmental interactivity	Object manipulation	Environment manipulation	No manipulation					

Figure 7: Taxonomy to delineate educational VR use cases

5. An Illustrative Demonstration: VR EasySpeech

The presented taxonomy was applied to the real-world use case "training presentations" by VR EasySpeech. The evaluation method of an illustrative scenario helps to indicate the taxonomy's applicability (Szopinski, Schoormann and Kundisch, 2019). VR EasySpeech offers VR scenarios for presentation training simulating a realistic audience (Dashöfer GmbH, 2023). The Baden-Württemberg Cooperative State University (DHBW) in Germany uses this application either as a standalone training tool for students or as an integrated component in courses (*www.dhbw.de*). VR EasySpeech works with the Pico G2 Enterprise VR glasses. The target audience are bachelor students from various higher-semester disciplines who want to improve their presentation skills. The authors of this study are actively engaged in training and testing this application.

Virtual reality. The application presents high-resolution visuals. Hence, the *vividness* is obtained as high. Students have reported that the application supports to lower the fear of public speaking and attribute this to the scenarios' realistic nature. Thus, *telepresence* is assessed as high. Consequently, a high *immersion* is observed. Due to the applications' goal (training in a realistic environment), the *3D environment* is appropriately realistic. *Sensory feedback* is primarily *visual* in line with the practice of speaking and presenting. The *autonomy in interaction* is rather low as the application offers a *deterministic world*, with three practice scenarios predefined: a meeting room, a conference room, and an auditorium.

Use case. The *trigger* of this use case is its *practicability*, as it allows students to improve their presentation skills independently and flexibly. The main *actors* are *educators*, *learners* (students) and *VR scenario developer* (VR EasySpeech developer). Since the use case includes three scenarios, the *richness* is rated as *multiple scenarios*.

Education. VR EasySpeech focuses on the *educational objectives* to both *apply* presentation skills and *evaluate* them through its integrated artificial intelligence (AI)-based assessment. The *aimed competency* is a *social-emotional* one which allows students to increase their confidence in presentation and improve their ability to interact in social contexts. Given the deterministic nature of the use case, the *autonomy in learning* is *externally imposed*, with the learning process strictly guided by the three scenarios and the embedded AI-based assessment. The *field of study* in which the use case was applied at the DHBW, was *engineering*. This was because the training was offered to engineering students.

Modalities. As VR EasySpeech allows interaction with simulated environments, the *purpose* is characterized as *interactivity* and the *technique* is defined as *simulation*. As the use case is designed for a single student practicing a presentation, the *user interaction* is defined as a *single user* interaction. The *interaction identities* are primarily *virtual actors* represented by a virtual audience. The primary *interaction mechanism* is *communication* focusing on exchanging information, either through the presentation itself or through feedback within the virtual environment. Finally, the *environmental interactivity* is defined as *no manipulation*, meaning that neither objects nor the environment can be changed. Figure 8 illustrates the taxonomy application.

Meta-Concept	Dimension	Characteristics		
Virtual reality	Immersion	Vividness (high)	Telepresence (high)	
	3D environment	Realistic environment		
	Sensory feedback	Visual		
	Autonomy in interaction	Deterministic world		
Use Case	Trigger	Practicability		
	Actors	Educator	Learner	VR scenario developer
	Richness	Multiple scenarios		
Education	Learning objectives	Apply	Evaluate	
	Aimed competencies	Social-emotional		
	Autonomy in learning	Externally imposed		
	Field of study	Engineering science		
Modalities	Purpose	Interactivity		
	Techniques	Simulation		
	User interaction mode	Single user		
	Interaction identity	Virtual actors		
	Interaction mechanisms	Communication		
	Environmental interactivity	No manipulation		

Figure 8: Applied taxonomy

This illustrative demonstration shows that the taxonomy is applicable in practice. In doing so, subjective ending conditions are fulfilled (Nickerson, Varshney and Muntermann, 2013): The taxonomy is explanatory because it helps to explain and describe VR use cases in educational contexts. Thus, the taxonomy is concise, as it consists out of four meta-concepts and can therefore be easy applied. Further, the taxonomy is extensible as new dimensions and characteristics can be easily added with the visualization as a morphological box (e.g., based on new findings of VR use cases). It is robust, as it is built up on state-of-the-art and use cases implemented. Finally, the taxonomy is comprehensive as it covers all relevant dimensions and characteristics by following an inductive (E2C) and deductive (C2E) approach (Nickerson, Varshney and Muntermann, 2013).

6. Discussion and Conclusion

The goal of this research is to offer a theory of analysis (Gregor, 2006) that is able to describe and classify VR educational use cases. The nature of the artifact chosen to offer such a theory was that of a taxonomy (Nickerson, Varshney and Muntermann, 2013). This taxonomy includes 17 dimensions and 37 characteristics derived from concepts related to *VR*, *use case*, and *education* in a deductive manner, complemented by modalities inductively derived from implemented VR use cases that are described by literature. The illustrative scenario demonstrates that the taxonomy helps precisely describe VR use cases in education. Use cases can be compared, and using an empirical approach, it may be possible in future research to explore patterns and archetypes of VR use cases in education.

The taxonomy offers both researchers and practitioners a robust tool for understanding, comparing, and discussing different types of VR use cases in education. Additionally, the taxonomy addresses the existing ambiguity around the configurations and applications of VR in education and brings attention to the subtleties and nuances inherent in this rapidly evolving field. For researchers, the taxonomy provides a systematic and consistent way of describing and analysing VR educational use cases. It serves as a foundation for further research, assisting in formulating precise research questions and hypotheses. For practitioners, including educators and curriculum designers, the taxonomy serves as a guide, assisting in the understanding, selecting, and implementing appropriate VR use cases for the specific educational context.

As the taxonomy is based on scientific literature, this work cannot generalize the presented findings without limitations. First, to address sample construction concerns (Larsen et al., 2019), conference proceedings were included in the SLR to mitigate publication bias. Second, the taxonomy covers the findings from the papers analysed. Accordingly, other dimensions and characteristics may predominate in other use cases. For example, the *autonomy in interaction* dimension lacks the constructivist world. While the open and deterministic worlds were evident in the studies, the use cases did not incorporate any constructivist approaches, where users actively shape and manipulate their environment. The inclusion of the constructivist world could reflect the shift towards lifelong learning (Qu and Zhang, 2022). Further, the dimension *sensory feedback* describes the three characteristics: *visual*, *auditory*, and *haptic*. However, this misses the olfactory and gustatory senses (Sorabji, 1971), which are either not yet integrated or not identified in the use cases of the SLR. Moreover, the *interaction identity* dimension, which currently includes *virtual objects*, *virtual* and *virtualized actors*, may need to consider the potential for virtualized objects in the future. These could be real-world objects introduced into the virtual environment using real-time scanning. Furthermore, for a proper application of the taxonomy, the implementation level of VR use cases lacks sufficient study. The analysed studies only sporadically describe how the VR use case was constructed and thus insufficient for inclusion in the actual taxonomy. Some of them mentioned data collection via 360-degree cameras (Dixon et al., 2020) or pre-built models from the Unity Asset Store (Neira, Castañeda and Torres, 2021). 3D software (Halabi, 2020) is described for modeling, and Unity 3D (Sunday et al., 2022b) or Adobe Captivate (Murphy, 2022) are mentioned as development platforms. The specific discussion of these features is currently too diffuse to be included in the current taxonomy and therefore represents an opportunity for future research. Last, as VR technology rapidly evolves, the taxonomy may require regular updates to remain relevant and applicable.

Future research should include the verification and potential expansion of the proposed taxonomy by incorporating a more extensive range of VR use cases in every field of education (Destatis, 2021). Crucially, future research should also evaluate the proposed taxonomy through its practical application to various use cases. Such real-world application and testing would offer insights into its operational efficiency, further validating or indicating necessary adjustments to the taxonomy. Based on the studies analysed, this taxonomy addresses the research gap highlighted by Zhang and Lin (2021) regarding the "(…) lack of in-depth research on the internal structure characteristics (…) of virtual learning." Won et al. (2023) also recommends "(…) identifying the unique characteristics of VR environments". Lastly, the taxonomy is a direct response to Radiantis' (2020) call "proposing a taxonomy of learning theories and other framing factors for educational VR applications is a future research task".

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