IMMERSIVE VIRTUAL REALITY IN EDUCATIONAL CONTEXTS: A CRITICAL ANALYSIS OF THE TEACHING AND LEARNING MODELS

LA REALTA' VIRTUALE IMMERSIVA NEI CONTESTI EDUCATIVI: UN'ANALISI CRITICA DEI MODELLI DI INSEGNAMENTO E APPRENDIMENTO

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ABSTRACT
The literature indicates an increasing focus on conducting empirical research concerning immersive virtual reality (IVR). Nonetheless, there exists a pressing requirement to articulate the theoretical models associated with the IVR-mediated teaching-learning process more explicitly. This study aims to delineate and critically evaluate the predominant models in the existing literature that pertain to the learning processes and instructional design mediated by IVR.

La letteratura indica una crescente attenzione alla conduzione di ricerche empiriche riguardanti la realtà virtuale immersiva (IVR). Tuttavia, emerge l’esigenza di articolare in modo più esplicito i modelli teorici associati al processo di insegnamento-apprendimento mediato dall’IVR. Questo studio si propone di delineare e analizzare criticamente i modelli predominanti nella letteratura esistente che riguardano i processi di apprendimento e la progettazione didattica mediati dall'IVR.

KEYWORDS
Immersive virtual reality; instructional design model; learning model; educational context.

Realtà virtuale immersiva; modelli di progettazione didattica; modelli di apprendimento; contesto educativo

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Introduction

This research endeavors to enhance the development of a comprehensive theoretical framework for employing IVR in educational contexts. It seeks to achieve this by identifying and scrutinizing established models of learning and instruction, thereby addressing the deficiencies noted in the literature. IVR has undergone significant evolution in recent years, extending its applications across a different range of fields, from therapeutic interventions to entertainment sectors. It also opens new frontiers for learning and teaching by offering unique, immersive educational experiences beyond the traditional limits of didactics. Despite the acknowledged potential of IVR for enhancing engagement and educational effectiveness, empirical research in this domain continues to encounter significant challenges. These include the complexities of creating a unified conceptual framework and language that clearly defines the phenomenon and the specific effects of IVR on educational methods. To address these challenges, a viable approach involves a thorough examination of the theoretical principles that guide the design and analysis of IVR-mediated educational environments. However, as has been extensively documented by several systematic literature reviews (Rubio-Tamayo et al., 2017; Jensen e Konradsen, 2018; Pellas et al., 2020; Radianti et al., 2020; Wu et al., 2020; Hamilton et al., 2021; Marougkas et al., 2023) persists a considerable lack of solid theoretical foundations that effectively support the formulation of hypotheses and the interpretation of data from educational research. This deficiency constrains the potential for advancing future studies that meet the requisite standards of scientific rigor. In fact, on the one hand, there is a frequent reliance on general theories that need to adequately integrate detailed conceptual frameworks, which should be defined as crucial components such as, interaction and immersion, which are essential for a practical IVR experience. On the other hand, the absence of longitudinal studies further complicates the ability to offer comprehensive theoretical and conceptual frameworks. These investigations further underscore the absence of established learning theories that could underpin research on learning outcomes and characteristics of instructional methodologies, a notably critical deficiency as articulated by Radianti et al. (2020) and Hamilton et al. (2021). Moreover, the comprehension and articulation of the concepts of reality and presence, as examined by authors like Daniel Mellet-d'Huart (2021), require further elaboration within educational frameworks. Although these concepts are vital for immersive experiences, their theoretical underpinnings remain underdeveloped. To effectively address this problematic situation, we began with an initial literature review based on the assumption that learning and teaching cannot be treated separately as they are closely interconnected (Tennyson, 2005). This step allowed us to identify, describe, and critically evaluate some theoretical and conceptual frameworks related to learning and teaching processes mediated by IVR, which had previously been elaborated and employed. The analysis focused on highlighting these frameworks' strengths and critical areas. The objective of this paper is to equip researchers with a robust tool that aids in constructing a sound theoretical framework, thereby enhancing the precision and rigor of research designs and the interpretation of collected data.

The structure is designed to offer a comprehensive understanding of the subject matter. In the initial section, the research examines the primary models that explicitly delineate the learning process within IVR environments. The subsequent section concentrates on instructional design models that are employed in crafting IVR-based educational frameworks. The third section offers a critical evaluation of both learning and teaching models pertinent to IVR usage, juxtaposing these with two established meta-models. The conclusion underscores the article's role in generating new research hypotheses and opening fresh research avenues, thereby sustaining the discourse on the application of IVR in education with a focus on technological precision and theoretical rigor.

1. The main learning models in IVR contexts

A critical foundation for examining learning models in IVR domains is encapsulated in the multimedia learning theory articulated by Mayer (2009). This framework delineates two predominant approaches to multimedia learning: a technology-centric approach, where software predominates, and an individual-centric approach, which emphasizes fundamental cognitive processes and the interaction between the individual and the system. The author considers both approaches and outlines the main objective of multimedia learning research: the ability to design environments that promote meaningful learning. However, in recent years, there has been a sudden development of different multimedia devices and new technologies. Indeed, the evolution from static images to animations, and subsequently to immersive virtual environments, signifies a pivotal shift in the design of educational experiences. Makransky (2022) emphasizes that this progression has introduced a fundamental element in the didactic architecture of such experiences: the immersion principle in multimedia learning. This principle, when integrated into virtual learning environments, is posited to significantly augment the learning experience.

Based on these premises, Makransky proposed two distinct models of the learning process developed within an IVR experience, which are outlined below to be critically analyzed in the third paragraph.

1.1 CAMIL

The Cognitive Affective Model of Immersive Learning (CAMIL)[1] formulated by Makransky (2021) posits a nuanced theory of change. This model articulates that the efficacy of IVR in educational settings does not inherently stem from the medium itself but rather from the pedagogical strategies employed within IVR contexts. Specifically, it asserts that carefully designed instructional methods can effectively leverage the unique affordances of IVR technologies. Furthermore, CAMIL adopts a theoretical stance that emphasizes the dynamic interaction between the medium and instructional methods. This model also suggests that motivational and educational theories previously applied to less immersive media are potentially extendable to enhance learning experiences in immersive environments.

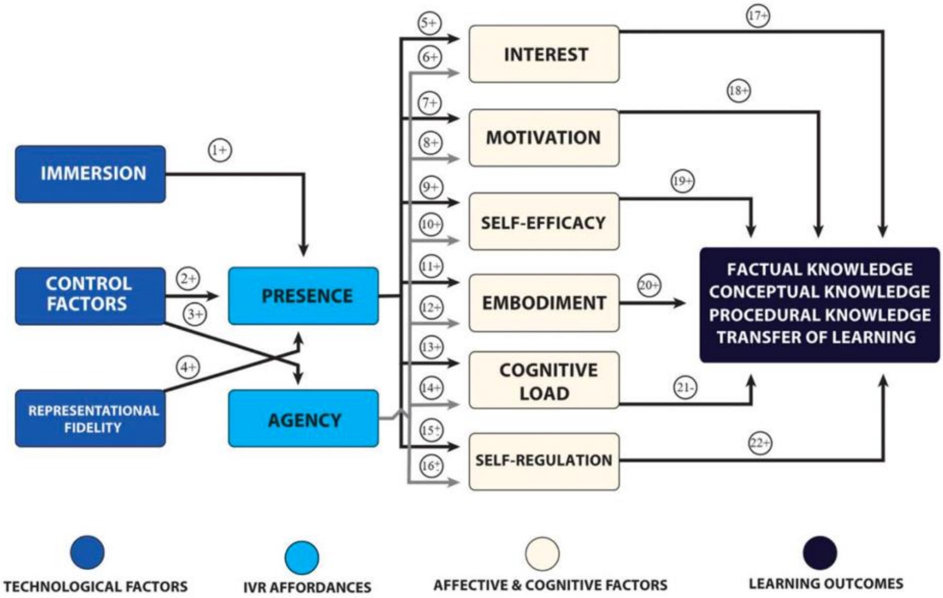

Figure 1: Overview of the CAMIL (Makransky et al. 2021).

Within the context of a learning activity that incorporates IVR, the model initially addresses technological aspects (immersion, control factors, and representational

[1] Makransky's model was developed through a rigorous empirical methodology, which entailed the systematic verification of the interrelationships among its constituent variables.

fidelity). These technological dimensions critically shape two fundamental psychological constructs in IVR-based learning: presence, which is defined as the sensation of "being there," and agency, which refers to the capacity to generate and control actions that alter the virtual environment and its components. In particular, the model describes how presence and agency have an influence on the learning of factual, conceptual and procedural knowledge, as well as on its transfer, mediated by a series of affective and cognitive factors[2]: interest; intrinsic motivation sustained by curiosity; the perception of self-efficacy; embodiment[3]; cognitive load; self-regulation of behavior. Although not explicitly represented in Fig 1, Makransky (2021) acknowledges additional variables that may impact the model's applicability. These variables encompass demographic factors such as age, previous experience, health conditions, personal traits, and behavioral dispositions. An understanding of these factors is vital for effectively applying the model, highlighting the significance of specialized knowledge in these domains. The model's flexible design allows for its application across a diverse array of immersive experiences, ranging from interactions with virtual avatars to engagements within authentic 360-degree environments, thereby demonstrating its extensive adaptability.

1.2 TICOL

Considering increasing interest in collaborative learning methodologies, Makransky (2023) conducted a comprehensive examination of the pedagogical advantages and constraints associated with Extended Reality-Supported Collaborative Learning (XRCL). This investigation led to the development of the Theory of Immersive Collaborative Learning (TICOL)[4], which seeks to establish a theoretical framework capable of delineating the distinctive factors that define collaborative learning experiences within immersive environments[5].

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[2] Please refer to the original article for details and bibliographical references on the individual concepts.
[3] Winn (2002) proposed that learning in artificial environments could be enhanced by embodiment, embeddedness, and dynamic adaptation. This observation led to the need to define a new paradigm: the "paradigm of enaction" (Mellet-d'Huart, 2021).
[4] The authors use the term theory. However, given the elements examined and their structuring, it is possible to identify it as a model comparable to CAMIL.
[5] Some of the relationships hypothesized by the model are the outcome of empirical research. In contrast, others are only hypothesized theoretically by extension of traditional collaborative learning models to collaborative learning situations with IVR of the model.

It is based on a theoretical framework that draws on the principle of immersion in multimedia learning (Makransky et al., 2022) and CAMIL (Makransky et al., 2021).

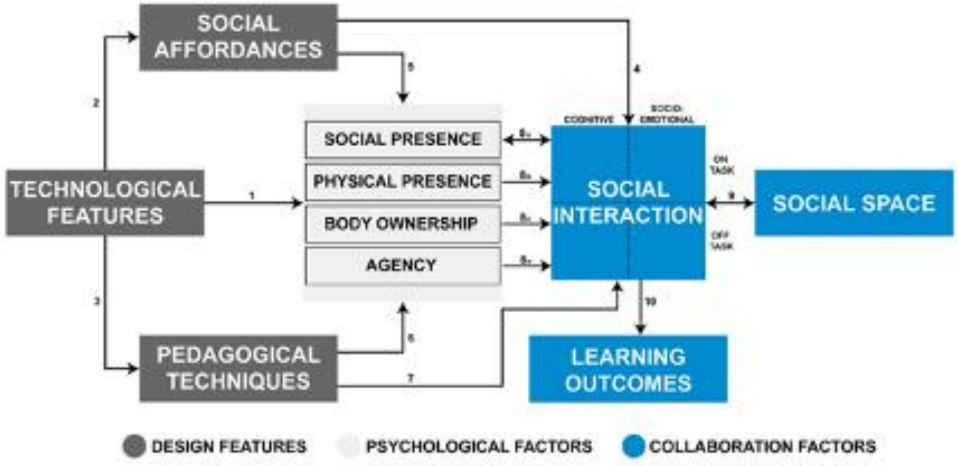

Figure 2: Overview of the TICOL (Makransky et al. 2023).

TICOL (Fig. 2) hypothesises that three contextual variables (*social affordances*, *technological features*, *pedagogical techniques*) influence the level of four psychological variables closely related to the use of the IVR: *social presence*, *physical presence*, *body ownership* and *agency*. Furthermore, TICOL hypothesizes that these factors may influence collaborative learning, specifically the three main aspects that characterize it: *social interaction*, *social space* and *learning outcomes*. According to TICOL, the pivotal aspect of developing efficacious learning tools in XRCL environments lies in comprehending the interplay among design characteristics, psychological elements, and factors related to collaboration. It is important to note, however, that the construct of "body ownership" plays a significant role within this framework - the «sensation that arises in conjunction with being inside, having, and controlling a virtual body» (Makransky et al., 2023, p. 8) - highlights that the use of this model was primarily conceived within immersive virtual experiences involving the presence of virtual avatars.

2. The main teaching models in IVR contexts

The enhanced availability and accessibility of IVR devices have catalyzed their increased utilization within educational settings. To ascertain the most effective strategies for employing IVR in education, Castelhano et al. (2023) conducted a systematic review and identified the four most prevalent Instructional Design (ID) frameworks/models[6]: XR ABC Framework (Shippee et al., 2021); iVR Learning (M-iVR-L) Framework (Mulders, 2022); TESLA Instructional Design Model (Fragkaki et al., 2019); Castronovo et al. Design Model (Castronovo et al., 2019). To these it was deemed appropriate to add Instructional Design Model for Immersive Virtual Reality Learning Environments identified by Tacgin et al. 2021.

We will also give a brief description of these and then critically analyze them in the following paragraph.

2.1 XR ABC Framework

The XR ABC Framework establishes a unified approach and terminology for designing, developing, and describing IVR learning experiences, which are distinguished by their interactive components. The framework was developed as part of teaching activities aimed at Chinese medical university students. It comprises three phases: 1) the 'absorb' phase involves the use of different immersive tools to support comprehension and recollection experiences; 2) the 'blend' phase, which allows users to modify existing content by using the available apps and experiences to manipulate or move objects to apply, analyze and evaluate the content; 3) the 'create' phase, characterized by learning moments and experiences that allow the creation of new content. This phase enables students to apply their creativity and innovation by constructing unique and novel objects within VR environments. Through this mechanism, the XR ABC Framework seeks to enhance student engagement and learning capabilities by facilitating a deeper theoretical comprehension via simulated experiences, thereby promoting active and creative involvement.

2.2 iVR Learning (M-iVR-L) Framework

The iVR Learning (M-iVR-L) Framework delineates a structured approach for the instructional design of vocational training targeted at apprentices in the automotive industry. This framework is comprised of six distinct phases, designed as guidelines to bolster, and refine the learning process mediated by IVR: *learning first, immersion second*: it is necessary to emphasize the learning process over

[6] The authors used *framework* as a synonym for *model*.

immersion, which is only used if it is required to achieve the learning objectives; *segment complex tasks into smaller units*: it is necessary to divide the content into several sessions to avoid overloading the students; *provide learning-relevant interactions*: prevent interactions that are not relevant to learning; allow pre-training to students, covering both fundamental concepts and interactive tools; *guide immersive learning*: invest in guidance while using the IVR to provide moments of learning acquisition without the increased load provided by the tool becoming an impediment; *build on existing knowledge*: use the learner's prior knowledge to introduce new concepts and tools, such as the IVR, to test the learners' level of expertise and the support they need; *provide constructive learning activities*: provide constructive learning activities that enable the learner to build knowledge and apply it to new tasks, inside or outside immersive scenarios.

The iVR Learning (M-iVR-L) Framework is instrumental in harmonizing technological applications with educational strategies. It meticulously calibrates the utilization of IVR throughout various stages of the educational continuum. This strategic calibration seeks to maximize learning efficacy and enrich the immersive educational experience, thereby advancing the overall quality of the learning process.

2.3 TESLA Instructional Design Model

The TESLA model was developed as part of an initiative to equip programmers and pre-service teachers, with the skills to design educational interventions using IVR. This model synthesizes elements from two instructional design frameworks—ASSURE and TPACK—and incorporates Kirkpatrick's evaluation model to provide a comprehensive approach to training design. Within the TESLA framework, the ASSURE model serves as the foundational design structure, delineated into six sequential stages represented by the acronym: Analyze, State Standards, Select Strategies, Technology and Resources, Utilize Technology and Resources, Require Learner Participation, and Evaluate and Revise. This integration facilitates a systematic approach to designing and assessing IVR-based educational interventions, ensuring alignment with pedagogical objectives and technological capabilities. The TPACK model was integrated into the fourth phase of the ASSURE model to ensure the development of a critical conception of the technology by always foreseeing a close interaction between three primary forms of knowledge: content knowledge, pedagogical knowledge, and technological knowledge.

Finally, Kirkpatrick's model was integrated into the last phase of the model to identify the objects of project evaluation: reactions, learning, behavior, and overall project results.

The integration of diverse instructional strategies within the TESLA model aims to provide a holistic framework that not only facilitates the acquisition of technical skills but also fosters the development of robust pedagogical foundations.

2.4 Castronovo et al. Design Model

Castronovo et al.'s (2019) instructional design model was developed for training interventions targeting university students in construction engineering. The interventions utilized an IVR educational game designed to facilitate students' critical engagement with building construction design. For the development of this game, the team employed the first three phases of the ADDIE framework—analysis, design, and development—as outlined by Allen et al. (2006). Concurrently, the educational experiences were structured using a model from the Center for Educational Technology at Florida State University. This model is notable for its flexibility and integration of both behavioral and cognitive insights, reflecting contemporary interdisciplinary research in educational methodology (Morrison, 2011). In the *analysis* phase, the first two steps were to identify the target audience and the environment for the design review simulator (DRS). Subsequently, the training objectives were identified. In the *design* phase of the game, four components were created: game story, mechanics, user interface, and interaction. Finally, in the *game development* phase, the research team developed: 1) VR interfaces and a relatively easy transfer of building information modeling; 2) instructional materials and evaluations to facilitate the integration of the game into educational settings.

2.5 Instructional Design Model for Immersive Virtual Reality Learning Environments

The instructional model developed by Tacgic & Dalgarno (2021) aims to establish an Immersive Virtual Reality Learning Environment (IVRLE) tailored for training nurses in surgical procedures. This model draws upon the foundational theoretical principles identified by Dalgarno (2010) and builds upon the initial myVOR model by Tacgin (2017), which exhibited certain limitations. Addressing these shortcomings, this study introduces the myVOR 2.0, employing a design-based research methodology to elucidate the interrelationships among theory, design, and implementation, while weaving together the principles of learning and teaching. As depicted in Figure 3, the development of an IVRLE necessitates meticulous consideration of two primary areas that significantly impact the spectrum of learning afforded—encompassing concepts, phenomena, procedures, rules, and attitudes:

1) the macro area related to *activating learning using adequate strategies* that encompasses: a) set of modes of presentation of the learning content; b) didactic strategies and techniques to support learning; c) characteristics of the participants; 2) the macro-area of immersive environmental design is integral to the instructional model, encompassing essential hardware and software characteristics (sense of presence, high fidelity environments, and interactivity). These elements distinguish the design of a learning environment within an IVR setting from traditional, non-immersive educational frameworks. Tacgin et al. (2021) highlight that these attributes are crucial in enhancing the authenticity of the Immersive Virtual Reality Learning Environment (IVRLE), which is pivotal for augmenting users' perceptual experiences. This authenticity is deemed essential for effectively simulating realistic scenarios that foster deeper learning and engagement.

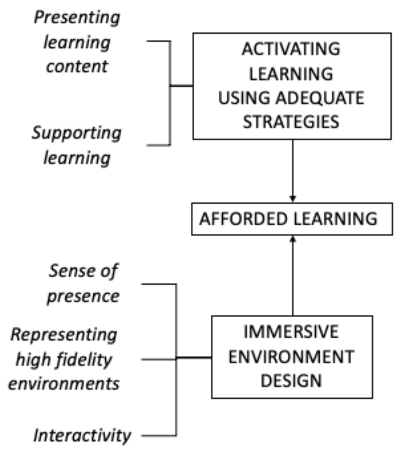

Figure 3: overview of the Istructional Design Model for Immersive Virtual Reality Learning Environments (Tacgic & Dalgarno, 2021) [Adaptation made by the authors].

3. Elements for a critical analysis of the identified models

To proceed to a first critical analysis of the learning and didactic models related to the use of the IVR presented in the previous paragraphs, we have chosen to compare the models described above with a meta-model to highlight the authors' choices regarding the presence or absence of dimensions, variables, and relationships[7].

In addressing the learning process, the meta-model utilized in this study is derived from Illeris (2012; 2018), which represents a refined iteration of the comprehensive learning model. Concurrently, the instructional design framework employed here is informed by an adaptation of the theoretical contributions from Reigeluth & Moore (1999) and Reigeluth & Keller (2009), integrating their insights into the instructional design process.

3.1 The learning process metamodel

Several scholars have sought to consolidate diverse models that describe the learning phenomenon into a unified theoretical framework. Engeström (1987), notably, advocated for a comprehensive approach to learning theory, emphasizing the necessity to address four fundamental components: the learner, the motivations for learning, the processes involved, and the content and outcomes of the learning experience. This perspective posits that a holistic understanding of learning must incorporate these integral elements to effectively encapsulate the complexity of educational dynamics. Jarvis (2006, p. 198) believes, that at least four elements should be present in a learning theory: «the person, as learner; the social situation within which the learning occurs; the experience that the learner has of that situation; the process of transforming it and storing it within the learner's mind/biography. Each of these four elements has innumerable, interacting variables, and different theories have highlighted different variables».The realization, however, is that each of the theories of learning «adds a little bit more to our understanding of human life and learning, but we do not and cannot know everything about it» (p. 199). Illeris (2012; 2018) represents a notable figure among scholars who have endeavored to synthesize various models of learning into a unified framework. His creation, the comprehensive learning model, integrates the elements highlighted by Engeström and Jarvis, providing a holistic view of the educational process. Fig 4 illustrates an adapted version of this model at its

[7] We speak of a first critical analysis because here, we have favored the completeness of the model as an unique criterion of judgment.

foundational descriptive/prescriptive level. This model articulates two primary processes—elaboration/acquisition and interaction—and delineates three critical dimensions: content, incentives, and environment. This framework serves to facilitate a deeper understanding of the interplay between educational theory and practice.

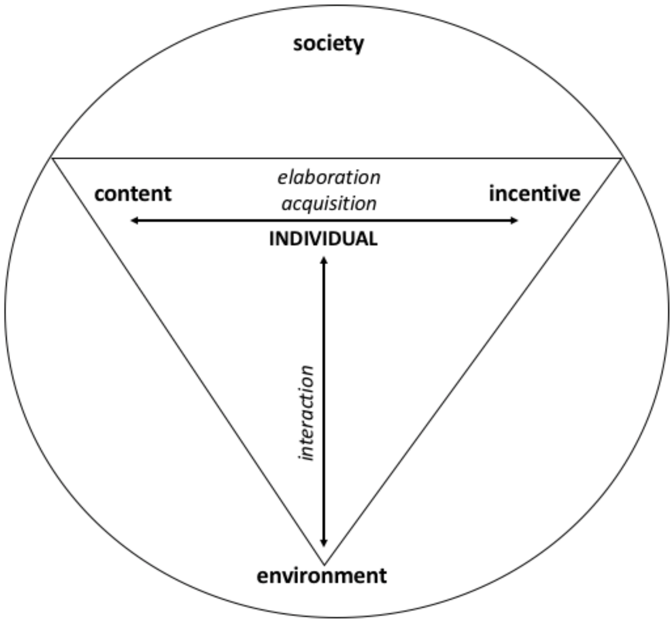

Figure 4: summary model of specific learning models (Illeris, 2012; 2018).

In the theoretical model, the individual represents the central node around which all dimensions and processes are oriented. The first process, represented by a vertical bi-directional arrow, entails the individual's interaction with their environment. The second process, depicted by a horizontal bi-directional arrow, relates to the psychological processing and assimilation of stimuli and influences emanating from this environmental interaction. Although distinct, these processes are integral to learning and generally occur simultaneously. Specifically, the acquisition process entails synthesizing new stimuli and influences from the environment with existing knowledge, thereby endowing the resultant learning with a unique individual character. Structured around a triangular framework, the model posits three dimensions at its vertices: content, incentives, and environment, with the first two actively engaged in the acquisition process. This structural representation underscores the interconnectedness of these dimensions in shaping the learning experience. *Content*[8] is the set of knowledge, skills, opinions, insights, meanings, attitudes and opinions, values, conventions, habits, feelings, behavior, and working methods. The *incentive* is the elements (emotion, interest, need, inclinations, desires, volitions, duty) involved in the motivation underlying the 'mobilization of mental energy' necessary for the acquisition process. The third dimension is the *environment*.

The circle surrounding the triangle visually represents the sociocultural context within which all learning processes and dimensions are embedded and influenced.

The second level of the model delves into the specifics of the acquisition process, detailing the four primary types of acquisition determined by the integration and assimilation of learning inputs into existing cognitive schemata. Cumulation, the creation of a new schema that is not linked to any prior schema, representing novel learning that stands apart from previous knowledge. Assimilation, where new information is incorporated into an existing schema, enhancing, or modifying it without altering its fundamental structure. Accommodation, this occurs when new information cannot be readily integrated into existing schemata, prompting the learner to deconstruct and reconfigure their cognitive framework to accommodate the new information. Transformation, a profound reorganization of existing schemata that not only changes how new information is assimilated but also fundamentally alters the learner's conceptual framework or personal identity.

We assume Illeris's inclusive model here as a tool to guide the critical analysis of the learning models involving IVR outlined above.

3.2 A critical analysis of learning models

Prior to comparing the CAMIL and TICOL models with the meta-model, it is crucial to clarify the interpretation of the term 'environment' as utilized by Illeris (2018). Within his framework, 'environment' refers to all external aspects, both physical and virtual, that are external to the subject. This includes the tangible, real-world

[8] Illeris (2012) refers that everything that was not present at birth is acquired through learning.

environment as well as the virtual settings that subjects interact with through immersive interfaces. This distinction is fundamental for understanding the scope of influence these environments exert on the learning process as articulated in the subsequent analysis.

Upon analyzing the CAMIL model and its alignment with Illeris' meta-model, numerous correlations are evident. All components delineated by Makransky are accommodated within Illeris' framework. Specifically, the technological factors that define the environment's interface, mediated by physical devices, correspond to elements in Illeris' meta-model that describe the individual’s interaction with the environment. While the IVR affordances—presence and agency—are intimately associated with the interface of the instrument, they also significantly impact the individual's internal perceptions, thus contributing to internal processing activities. In terms of affective and cognitive factors, further scrutiny is essential. Interest, motivation, and self-efficacy are categorized within Illeris' meta-model as incentives, while cognitive load and self-regulation fall under internal processing. Embodiment occupies an intermediate position, straddling internal processing and environmental interaction. In the context of Makransky's CAMIL model, the identified learning outcomes are analogous to the 'content' dimension in Illeris' framework. However, it is noteworthy that the CAMIL model only indirectly incorporates the environmental variable through its virtual dimension, indicating a nuanced interpretation of the environment within IVR settings.

About the TICOL model, technological affordances and pedagogical techniques fit into the meta-model in the interaction between the individual and the environment. In contrast, social affordances and psychological factors are part of the internal processing. Finally, the learning outcomes identified by Makransky correspond to the "content" in Illeris's model. At the same time, social interaction and social space are in the internal elaboration process but also touch on the interaction with an environment that, as highlighted above, has a double dimension: real and virtual.

In conclusion, we can assert that the CAMIL and TICOL models can be effectively integrated within the Illeris meta-model. However, it's important to note that the social and environmental dimension, which is a significant aspect in educational contexts, is not explicitly addressed in CAMIL. Nonetheless, there is significant structural alignment between the models, with elements — cognitive, affective, and relational — clearly corresponding to the categories delineated by Illeris. This alignment indicates that the foundational principles and frameworks of these models are congruent, suggesting potential avenues for their integration.

3.3 A critical analysis of didactic process models

The metamodel utilized to critically examine the above instructional models incorporates the framework proposed by Reigeluth et al. (2009), enhanced by elements from earlier work by Reigeluth et al. (1999). Within their framework, instructional design theory is articulated as a collection of six interrelated design theories, each addressing distinct facets of instructional development. The cornerstone of these theories is the instructional-event design theory (IEDT), which specifies the desired characteristics of instruction and provides foundational guidance on instructional practices. The other five theories offer guidance about the following moments of the instructional activity: analysis, planning, building, implementation, and evaluation. Within the IEDT, all constructs of importance to instruction fall into two macro-categories: instructional methods (what the instruction should be like) and instructional situations (when it should be like that). Instructional methods are categorized into three primary groups, with an additional fourth category derived from Reigeluth et al. (1999): 1) instructional approaches, macro-strategies that define the overarching direction of instructional activities; 2) instructional components, detailed elements that can be customized based on specific instructional contexts as parts of an instructional approach; 3) content sequencing, methods for organizing educational content into coherent sequences with both approaches and components; 4) instructional relations, a newly integrated category that encompasses key elements such as control, grouping, interactions, and support for learning that Reigeluth et al. (1999) considered crucial for comparative analysis of instructional models. Instructional situations fall into two main subcategories: values about instruction and conditions of instruction. Values are about learning goals, criteria, methods, or who has power; conditions are about the nature of the content, the learner, the learning environment, or the instructional development constraints.

When comparing the five instructional design models discussed in the previous sections with Reigeluth's meta-model, several parallels and distinctions become evident. These findings have been systematically summarized in Tab 1.

MACRO-CATEGORIES (REIGELUTH)	CATEGORIES (REIGELUTH)	XR ABC Framework	IVR Learning Framework	TESLA	Castronovo et al.	Instructional Design Model for Immersive Virtual Reality Learning Environments
DIDACTIC METHOD	Didactic Approach		X	X		X
	Didactic Components		X			X
	Sequence of contents		X	X		
	Relations	X	X	X	X	X
DIDACTIC SITUATION	Values/Beliefs		X	X	X	
	Conditions	X	X	X	X	X

Table 1: depicting commonalities between Reigeluth's instructional design model and the ID models described above.

The XR ABC model primarily addresses components associated with relations and conditions, specifically focusing on the learning environment and consequently on resources (technological devices).

The IVR-L model exhibits the most extensive alignment with Reigeluth's framework, encompassing both instructional approaches and components. Specifically, it emphasizes the significance of coaching and guided practice in the use of IVR devices and tools. The model advocates for a procedural elaboration approach in content sequencing and addresses participant relationships and support mechanisms under the relations category. Additionally, it comprehensively considers the instructional situation, detailing learning objectives, learning types, and the initial characteristics and knowledge levels of learners.

The TESLA model exhibits significant alignment with Reigeluth's instructional design framework, particularly in content sequencing. This alignment is evident through the integration of the TPACK framework, which delineates the interaction among content, technological, and pedagogical knowledge. These latter knowledge types correlate with Reigeluth's categories of values and conditions, explicitly linking them to the learning environment and associated resources. Moreover, the TESLA model incorporates strategic elements necessary for achieving educational objectives, aligning with what Reigeluth categorizes as instructional approaches. Additionally, the model addresses the relations of instructional design, emphasizing support and participant involvement, as well as the mechanisms for controlling and evaluating learning processes.

Castronovo's model, which uses the ADDIE model as its reference, considers values and conditions, focusing on the elements concerning the recipients, the context, and the learning objectives. In this case, as in TESLA, the reference to the category of relations concerns the control phase of learning and, therefore, the evaluate moment.

The last model, Instructional Design Model for Immersive Virtual Reality Learning Environments, with the presenting learning contents refers to the category of didactic components of Reigeluth; while as far as supporting learning is concerned, the reference is to didactic approaches. The model focuses on afforded learning, i.e., the conditions, particularly the types of learning, which are largely influenced by the macro category of immersive environment design, which concerns what Reigeluth identifies as relations, understood in this specific case as the interaction between individuals and the objects used.

This analysis of instructional models within the context of IVR underscores the varied adherence to Reigeluth's instructional design framework. These models elucidate the adaptability of IVR in educational settings, yet they also highlight gaps in alignment with some of Reigeluth's core principles, such as 'instructional situations' and 'systematic assessments.' This misalignment could potentially detract from their effectiveness within traditional educational frameworks. A common focus on technological aspects and interactivity, often at the expense of pedagogical coherence and contextual integration, may curtail the educational potential of these models. Moreover, insufficient incorporation of 'instructional relationships' could limit meaningful interactions between educators and learners. To maximize the educational benefits of IVR, it is crucial to enrich these models with a holistic instructional design that integrates Reigeluth's established theoretical principles comprehensively. Additionally, while models like TESLA and iVR Learning incorporate elements reflective of learning theories, there is a notable absence of explicit discussion or direct integration of formal learning theories within these models, focusing instead on the practical and applied dimensions of pedagogy to enhance instructional outcomes.

Conclusions

Through the critical examination of learning and teaching models related to Immersive Virtual Reality (IVR) detailed in this paper, we have elucidated the diversity of approaches and the intricate challenges associated with applying IVR in educational contexts. The analysis reveals that despite the acknowledged potential of IVR, substantial obstacles persist, encompassing both theoretical and practical dimensions. Notably, the absence of a robust theoretical foundation for both learning models and instructional design is highlighted, complicating the rigorous development of educational interventions, interpretation of data, and identification of prospective research directions. This review corroborates the utility of models such as CAMIL and TICOL, which offer significant insights into the roles of immersion and interaction within learning environments. Nonetheless, the CAMIL model requires further enhancement to fully incorporate the social and environmental dimensions that critically shape immersive experiences. In terms of instructional design, while several essential elements for crafting effective IVR interventions have been identified, many models still overlook crucial variables, such as the methodologies for assessing learning outcomes post-IVR instructional activities. Despite the inherent limitations associated with the source data and the analytical-critical methodology employed, the findings of this study potentially provide scholars with valuable directions for advancing theoretical and empirical research. Among the prospective avenues for future research, a critical priority is the integration of learning process models with instructional design frameworks, thereby enhancing the coherence and efficacy of educational interventions utilizing Immersive Virtual Reality (IVR). Additionally, it is imperative to explore the inclusivity of theoretical and instructional approaches, particularly in relation to neurodivergent individuals or those from diverse social and cultural backgrounds. Further investigation into innovative assessment strategies and techniques that transcend traditional methods and incorporate virtual reality tools in educational settings is also crucial (Marcuccio et al., 2023). Moreover, it is essential for both policymakers and practitioners to acknowledge the significance of a robust theoretical foundation to guide the development of policies and empirical studies involving IVR, ensuring that such initiatives are not only technologically advanced but also grounded in solid theoretical principles.

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