

PERSPECTIVE

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# An integrative model of virtual reality supported immersive learning within a biographical stream of experiences

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## Abstract

Despite the growing use of virtual reality (VR) in education, theoretical accounts remain limited in explaining how a technologically mediated activity becomes part of a broader learning process. Existing frameworks provide valuable insights into cognitive and affective processes associated with VR use, but offer less systematic guidance on how prior experience, instructional preparation, task design, learner agency, educator facilitation, and subsequent reflection interact across an extended learning sequence. This paper presents the Integrative Model of Experience-Based Immersive Learning (I-MEIL), a conceptual framework that positions VR-supported activities within a biographical and pedagogically orchestrated stream of experiences. The model distinguishes between prior and preparatory experience, situated immersive experience, and reflective and transfer-oriented experience. It further differentiates technological immersion from subjective immersive experience and from immersive learning, thereby avoiding the assumption that VR use automatically produces presence, engagement, reflection, or learning. Technological features such as fidelity, interactivity, and multisensory representation are conceptualized as conditional possibilities for perception and action whose educational significance depends on represented content, instructional tasks, learner interpretation and agency, educator guidance, and the wider learning context. Across the three phases, cognitive, affective, and excitative response states are understood as dynamic and contingent processes that may contribute to cognitive, affective, attitudinal, behavioral, and psychomotor outcomes. By specifying how technological, individual, and pedagogical conditions are connected across time, the I-MEIL provides a design-oriented framework and a research agenda for examining preparation, situated engagement, reflection, and transfer in VR-supported learning.

## 1 Introduction

Virtual reality (VR) differs from many other digital learning technologies in the representational and interactive conditions it can provide. Depending on the technological configuration and the design of a particular application, VR systems can present spatially surrounding and sensorimotor-responsive environments that combine visual and



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auditory information with haptic or other sensory feedback. These features may create distinctive possibilities for perception, action, and situated engagement [18, 40, 47]. However, they do not determine whether learners experience presence, attend to relevant content, engage emotionally, reflect on what they encounter, or achieve particular learning outcomes [52]. The educational significance of a VR-supported activity therefore depends on the represented content, instructional tasks, learner characteristics and agency, educator facilitation, and the broader institutional and social context in which the activity is embedded.

Existing frameworks have substantially advanced theoretical understanding of learning with VR technologies. Reviews of VR research likewise document a strong emphasis on cognitive and affective learning processes and outcomes, while also pointing to growing attention to motivational and social dimensions [8, 77, 79]. The VR-specific Cognitive Affective Model of Immersive Learning [40] and Educational Framework for Immersive Learning [13], as well as the more general Cognitive-Affective-Social Theory of Learning in Digital Environments [61] describe relationships among technological characteristics, affective and cognitive processes, social factors, and learning outcomes. These frameworks provide important accounts of processes that may occur during interaction with digital or virtual learning environments. However, they offer less systematic guidance on how a VR-supported activity is connected with learners' prior experiences, how learners should be prepared for the technological demands of the activity, how tasks and educator facilitation shape engagement during VR use, and how subsequent reflection and transfer are pedagogically supported. The unresolved issue is therefore not whether cognition, affect, or social interaction matter during VR use, but how technological, individual, social, and instructional conditions are coordinated across an extended learning process.

This temporal and pedagogical extension is particularly important because technological immersion, subjective immersive experience, and learning represent analytically distinct phenomena [9, 52, 67]. Even an intense virtual experience becomes educationally relevant only insofar as learners engage with its content and connect it with prior knowledge, disciplinary concepts, personal perspectives, and possible courses of action [3]. The relationship between technological features, subjective experience, and learning must therefore be examined in conjunction with the instructional and learner-related conditions through which these connections are supported.

Research on generative learning further illustrates the importance of instructional activities surrounding the virtual episode. Activities such as explaining, summarizing, teaching, mapping, and reflecting can encourage learners to select, organize, and integrate information with existing knowledge [15]. Empirical studies on VR learning indicate that generative activities such as summarization, self-explanation, and collaborative processing can support learning when they are appropriately aligned with the instructional task [28, 38]. In VR-supported learning, such activities may be incorporated before, during, or after interaction with a virtual environment. Their effectiveness nevertheless depends on their timing, modality, cognitive demands, and alignment with the intended learning goals. Recent findings also indicate that transferring generative learning strategies to procedural learning contexts can be challenging and may create additional distraction when the activity is insufficiently integrated into the learning task [12]. Preparation and reflection should therefore not be treated as universally effective

additions, but as instructional components whose functions and design must be specified in relation to the content, task, technology, and learners.

The Integrative Model of Experience-Based Immersive Learning (I-MEIL) addresses this theoretical and design-oriented gap by positioning a VR-supported activity within a biographical and pedagogically orchestrated stream of experiences. The notion of a stream of experiences builds on the assumption that educational experiences derive their meaning from their relationship with preceding and subsequent experiences rather than from their momentary intensity alone. This understanding is informed particularly by Dewey's pragmatist conception of experience, according to which experience becomes educational through continuity, interaction, and reflective reconstruction [14]. It is also compatible with the broader concepts of learning, which direct attention beyond the acquisition of knowledge toward learners' developing relations to themselves, other people, and the world [5]. Within the I-MEIL, however, such development is not attributed to VR itself. VR-supported representations remain constructed and necessarily limited encounters that learners interpret from their own social, cultural, and biographical positions.

The I-MEIL furthermore distinguishes three interrelated phases: prior and preparatory experience, situated immersive experience, and reflective and transfer-oriented experience. The first phase includes learners' biographical and educational backgrounds as well as instructional preparation, such as activating prior knowledge, clarifying the task, establishing expectations, and developing technical familiarity. The second phase concerns learners' situated interaction with the designed VR environment and the cognitive, affective, and excitative response states that may arise within it. The third phase comprises pedagogically supported opportunities to articulate, contextualize, critically appraise, consolidate, and transfer what was experienced. These phases are not conceived as automatically completed stages or as a fixed causal sequence. Rather, they identify analytically distinct yet interdependent parts of a learning design whose relationships vary according to learners, tasks, content, facilitation, and context.

The framework makes three contributions. First, it differentiates technological immersion, subjective immersive experience, and immersive learning, thereby avoiding the conceptual equation of VR use with engagement or learning. Second, it extends the analytical focus beyond the virtual episode by describing how prior experience, preparation, situated engagement, reflection, and transfer are connected across time. Third, it translates these relationships into design considerations and empirically examinable propositions concerning learner agency, task design, educator facilitation, technological affordances, response states, and multidimensional learning outcomes. The I-MEIL thus conceptualizes VR not as an autonomous educational intervention, but as one possible representational and interactive component within a broader process of pedagogically designed experiences.

The remainder of the paper first defines VR and distinguishes technological immersion from subjective immersive experience and immersive learning. It then develops the theoretical role of experience, instructional framing, preparation, situated engagement, reflection, and transfer in VR-supported learning. Subsequently, the components and relationships of the I-MEIL are presented, followed by implications for empirical research and instructional design.

## 2 Theoretical background

### 2.1 Technological immersion, immersive experience, and immersive learning

VR encompasses a range of technologies used to generate and interact with computer-mediated three-dimensional environments. Mikropoulos and Natsis ([47], p. 769) define VR as “a mosaic of technologies that support the creation of synthetic, highly interactive, three-dimensional spatial environments that represent real or non-real situations”. This definition appropriately characterizes VR in terms of its representational and interactive functions without presupposing particular psychological or educational effects. However, VR systems can simulate real, inaccessible, hazardous, costly, or imagined situations and make them available for exploration and practice under controlled conditions [78].

VR technologies vary considerably in their configurations. Desktop-based systems typically present a virtual environment on a conventional screen and enable interaction through devices such as a mouse, keyboard, or joystick [42]. Head-mounted displays can visually surround the user and track movements of the head, body, or hands, while controllers, hand tracking, or additional sensors may enable different forms of interaction with the virtual environment [40, 56]. These configurations should not be arranged on a simple continuum from educationally inferior to educationally superior. Rather, they provide different combinations of representational and interactive possibilities whose appropriateness depends on the intended activity, learners, content, and context.

To avoid conceptual ambiguity, the I-MEIL distinguishes three analytical levels: technological immersion, subjective immersive experience, and immersive learning. *Technological immersion* refers to objectively describable properties of a media system that determine the extent and form in which sensory information, user actions, and system responses are coordinated [9, 47, 59]. Relevant properties include representational fidelity, interactivity, sensorimotor contingency, and the range of sensory channels addressed. These properties are characteristics of the technological arrangement rather than characteristics of the learner’s psychological state. *Subjective immersive experience* refers to the situated and temporally variable ways in which learners perceive and interpret their interaction with a virtual environment. Such experiences may involve presence, engagement, embodiment, perceived agency, or attentional absorption, but none of these responses is inherent in the technological system [9, 35, 67]. Learners using the same application and technological configuration may experience these phenomena to different degrees or not at all. Their responses may also fluctuate during the activity because of distraction, task difficulty, technical disruption, physical discomfort, prior experience, personal relevance, or deliberate disengagement. An immersive experience should therefore be treated as an empirically examinable and potentially discontinuous subjective event rather than as a necessary consequence of wearing a VR headset. *Immersive learning* constitutes a third and broader analytical level. In the I-MEIL, it refers to a pedagogically designed process in which a potentially immersive technologically mediated activity is connected with learners’ prior experiences, instructional preparation, situated tasks, educator guidance, and subsequent opportunities for reflection and transfer. Immersive learning is therefore not synonymous with technological immersion or with a subjective feeling. Technological immersion may provide conditions for particular forms of perception and action. Learners may or may not develop an immersive experience under these conditions, and such an experience may or may not become educationally

meaningful. Learning emerges, if at all, from the conditional interaction of technological, individual, social, and instructional factors across the broader stream of experiences.

Within this distinction, technological features are best understood as affordances rather than direct causes of experience or learning. In Gibson's [20] sense, *affordances* describe possibilities for action that arise in the relationship between an environment and an acting individual. A feature does not possess the same affordance independently of the learner, task, and context. For example, the possibility of manipulating a virtual object may support procedural exploration when the manipulation is aligned with a learning goal, but it may be irrelevant or distracting when it is peripheral to the task. Similarly, multisensory information may contribute to orientation or realism in one application while increasing unnecessary processing demands in another. Fidelity, interactivity, and multisensory representation therefore acquire educational significance only through their relation to the represented content, pedagogical purpose, learner interpretation, and instructional design.

The representational nature of VR also places limits on claims concerning perspective-taking and identity [66]. Virtual environments can present situations from a particular visual or spatial position and can invite learners to consider the experiences of other people. However, occupying a first-person visual perspective or controlling an avatar does not reproduce another person's cognitive standpoint, identity, or lived experience. Learners continue to interpret the representation from their own biographical, social, and cultural positions. Especially when virtual simulations address marginalization, discrimination, homelessness, migration, or other socially sensitive experiences, perspective-taking must not be equated with "becoming" another person [43, 71]. Such claims risk reducing socially and historically situated identities to temporarily consumable representations, a problem discussed, for example, in cybernetic tourism [53].

This three-level distinction establishes the conceptual basis for the I-MEIL. VR technology provides particular representational and interactive conditions, subjective immersive experiences describe learner responses to those conditions, and immersive learning denotes the broader pedagogical process through which a VR-supported activity may be connected with prior experience, conceptual understanding, reflection, and transfer. The following section develops the concept of experience underlying this process and clarifies why the educational meaning of a virtual episode depends on its relationship with preceding and subsequent experiences.

## 2.2 Experience as the foundation of immersive learning

The concept of experience is central to the I-MEIL because the educational significance of a VR-supported activity cannot be understood by examining the technological episode in isolation. An event becomes an experience not merely because it occurs, but because it is perceived, interpreted, and related to what an individual has previously encountered, understood, valued, or expected. Experience is therefore neither a property of VR technology nor a direct synonym for exposure to a virtual environment. It denotes a relational process that emerges through the interaction of the learner, the represented situation, the instructional task, and the wider social and pedagogical context.

This understanding is grounded primarily in Dewey's pragmatist theory of experience. Dewey [14] distinguishes between the occurrence of an experience and its educational quality. Not every experience is educative, and some experiences may even

restrict subsequent learning by reinforcing misconceptions, producing disengagement, or narrowing future possibilities for action. Two principles are especially relevant to the I-MEIL: continuity and interaction. *Continuity* means that every experience draws on preceding experiences and influences the conditions under which later experiences are interpreted. *Interaction* refers to the relationship between the learner's existing dispositions and the objective conditions of a situation. Accordingly, the meaning of a VR-supported activity emerges neither solely from the learner nor solely from the virtual environment, but from their situated interaction within a particular instructional arrangement.

The principle of continuity provides the theoretical basis for the biographical stream of experiences. Learners do not enter a virtual environment as neutral recipients of technologically presented stimuli. They bring prior knowledge, expectations, values, emotions, media experience, social positions, and culturally shaped interpretive frameworks. These biographical and educational conditions influence what they notice, how they interpret a represented situation, whether they regard it as personally or disciplinarily relevant, and how they respond to the available possibilities for action. The same virtual scenario may therefore become a challenging learning opportunity for one learner, confirm an existing understanding for another, or remain irrelevant, confusing, or unsettling for a third.

Within the I-MEIL, the term biographical does not imply that every VR-supported learning activity must address intimate life history or produce personal transformation. Rather, it emphasizes that learning is always connected with learners' historically developed relations to themselves, to other people, to knowledge, and to the world. This understanding is compatible with the German concept of *Bildung*, which extends educational analysis beyond the acquisition of isolated knowledge or skills toward changes in these relations [5]. Such changes cannot be attributed to the intensity of a virtual episode. They may emerge only when learners actively relate an experience to prior assumptions, encounter tensions or alternative interpretations, and reconsider their existing orientations through subsequent reflection and action. Such relating is supported when instructional activities make connections between the virtual encounter and learners' existing knowledge or assumptions explicit. Guiding questions, comparison tasks, self-explanation, or collaborative discussion can prompt learners to identify correspondences and discrepancies between what they expected and what they encountered.

The educational quality of an experience is therefore not determined by its sensory richness. A technically complex or subjectively intense VR activity may remain educationally superficial, whereas a comparatively simple simulation may become meaningful when it is closely aligned with a relevant question, appropriately facilitated, and connected with prior and subsequent activities. Its educational significance thus depends on how the experience becomes related to conceptualization, critical appraisal, and transfer.

Experience should also be conceptualized as temporally extended and potentially discontinuous. Learners' attention, presence, emotional involvement, and sense of agency may fluctuate throughout a VR-supported activity. Technical interruptions, cybersickness, distraction, unclear tasks, excessive demands, or deliberate disengagement may disrupt the experience [45, 66]. Conversely, learners may become deeply involved only during particular moments. The I-MEIL therefore does not assume one continuous immersive state. Instead, it treats the virtual episode as a sequence of situated encounters

whose meaning may change as learners act, receive feedback, redirect their attention, or reinterpret the situation.

This view is consistent with approaches that conceptualize experientiality as a matter of degree rather than as a binary distinction. Gibbons and Hopkins, [19] for example, distinguish different levels, modes, and forms of experiential activity, thereby demonstrating that the educational quality of experience depends on what learners are permitted and required to do rather than on mere participation in an activity. Applied to VR-supported learning, this means that experiential quality may vary according to whether learners merely observe a representation, explore it, make consequential decisions, practice procedures, collaborate with others, or critically investigate the assumptions embedded in the simulation. The use of VR does not itself establish a high degree of experientiality.

The experiential quality of a learning activity therefore depends on how these elements are coordinated. Task demands specify what learners are expected to notice, decide, explain, or perform. Learner activity determines how actively they engage with these demands. Feedback makes consequences, errors, or discrepancies available for further processing. Responsibility gives learners meaningful influence over decisions or actions, and opportunities for interpretation allow them to connect what occurred with disciplinary concepts, prior experience, and subsequent action. Experientiality is therefore enhanced not by activity alone, but when learners' actions have an intelligible relationship with the task and generate information that can be interpreted and used for further learning.

For empirical research, experience cannot be captured through a single indicator. Technological properties can be documented through system characteristics and interaction possibilities, whereas subjective experience requires evidence concerning how learners perceived and interpreted the activity. Depending on the research question, such evidence may include self-reports, behavioral and interaction data, verbal protocols, observations, interview accounts, written reflections, and physiological measures. These indicators should not be treated as interchangeable. For example, a high presence score documents a particular subjective response but does not demonstrate conceptual understanding, reflection, or learning. Likewise, behavioral interaction with a virtual object does not by itself reveal how the learner interpreted that action. Empirical examinations of the I-MEIL should therefore combine indicators across phases and explicitly distinguish technological conditions, subjective response states, meaning-making processes, and learning outcomes.

The experiential perspective underlying the I-MEIL consequently shifts the analytical focus from what VR supposedly does to learners toward how learners encounter, interpret, and integrate a technologically mediated situation within an ongoing educational process. Prior experience conditions the virtual encounter, the encounter may confirm, extend, disturb, or leave existing orientations unchanged, and subsequent instructional activities may support learners in articulating and reconstructing its meaning. The following section examines how this process can be pedagogically framed across preparation, situated activity, reflection, and transfer.

### 2.3 Instructional framing across the stream of experiences

If the educational meaning of a VR-supported activity arises from its relationship with preceding and subsequent experiences, instructional design cannot be limited to the construction of the virtual environment itself. It must also address how learners enter the activity, what they are asked to notice and do while using VR, how educators support their engagement, and how the experience is subsequently articulated and contextualized. The I-MEIL therefore treats preparation, situated facilitation, and reflection and transfer as distinct but interdependent instructional functions within the stream of experiences.

These functions are not exclusive to VR-supported learning. Preparation, scaffolding, discussion, and reflection are established elements of instructional design [26]. Their inclusion in the I-MEIL is justified not because VR automatically requires or generates them, but because particular characteristics and limitations of VR-supported activities create specific design demands. Learners may need to coordinate unfamiliar interfaces, bodily movements, spatial representations, and instructional information while their access to the physical and social environment is partially restricted by a head-mounted display. Attention may be captured by salient but instructionally peripheral elements, interaction demands may compete with conceptual processing, and technical disruption or physical discomfort may interrupt engagement. The instructional phases surrounding and accompanying VR use therefore serve particular orienting, regulatory, contextualizing, and integrative functions [71].

Prior and preparatory experience establishes the conditions under which learners encounter the virtual activity. This phase connects the designed learning sequence with learners' existing knowledge, expectations, experiences, and concerns. It may include the activation or assessment of prior knowledge, clarification of learning goals, introduction of relevant concepts, technical familiarization, safety information, and orientation to the available interactions. Preparation may also address the epistemic status and limitations of the simulation by clarifying what has been selected, simplified, reconstructed, or omitted [71]. This is especially important when a virtual environment represents ethically sensitive situations [34, 66]. Preparation does not predetermine how learners will interpret the activity. Instead, it provides conceptual, technical, and critical resources that may enable more focused and informed engagement.

The during-experience phase concerns the situated organization and facilitation of learners' interaction with the virtual environment. Instructional tasks and educator support jointly influence which possibilities for perception and action become educationally relevant. Tasks can direct attention toward particular relations, invite comparison or decision-making, require the application of disciplinary knowledge, or create opportunities for procedural practice. At the same time, poorly aligned prompts, excessive interaction requirements, or additional activities may divide attention and interfere with performance. Educator facilitation may occur through prior task instructions, in-environment scaffolds, or adaptive feedback, depending on the technological configuration and instructional setting [71]. However, facilitation should not be understood as technological control over learners' experience, but as the pedagogical provision of orientation and support while preserving learners' capacity to interpret, question, resist, or disengage.

The need for careful alignment is illustrated by research on generative learning activities [15]. Explaining, summarizing, teaching, mapping, and collaborative processing can promote the selection, organization, and integration of information when they are connected with the intended learning processes [28, 38, 57]. However, these activities should not be assumed to improve learning merely because they are added to a VR lesson. Delgado and Mayer [12], for example, examined focused explanative questions inserted during pauses. Their study demonstrates the importance of testing whether a generative strategy established in other learning contexts transfers effectively to learning in VR rather than presuming that its benefits will remain unchanged. Generative activities may support learning, have no additional benefit, or create competing demands depending on their timing, complexity, modality, and relation to the primary task [50]. The I-MEIL therefore treats instructional activities as conditional design elements rather than universally effective interventions.

Reflection and transfer constitute the post-experience instructional function. Removing a headset marks the end of the technological interaction but not necessarily the end of learners' processing of the activity. Learners may leave the virtual environment with fragmented impressions, unresolved emotions, uncertain interpretations, misconceptions, or unanswered questions [34]. They may also experience the activity as unremarkable or irrelevant. Reflection cannot be assumed to occur spontaneously or to reach a particular depth. Educators can create opportunities in which learners are invited to recall significant moments, articulate interpretations, compare perspectives, connect observations with disciplinary concepts, and critically assess the design and limitations of the representation [71]. However, reflection after VR use has several potentially distinctive objects. Learners can consider not only the represented content but also how the technological mediation shaped what they noticed, felt, or were able to do. They may examine how visual perspective, avatar representation, interaction possibilities, narrative structure, or system feedback influenced their interpretation. In ethically sensitive applications, reflection can explicitly distinguish between encountering a constructed representation and understanding another person's lived experience [34]. It can also make visible what the simulation omitted, whose perspective was privileged, and how the learner's own prior assumptions shaped the encounter. The specificity of post-VR reflection therefore lies not in a unique reflective mechanism, but in the need to critically reconstruct the relationship among represented content, technological mediation, learner interpretation, and educational purpose.

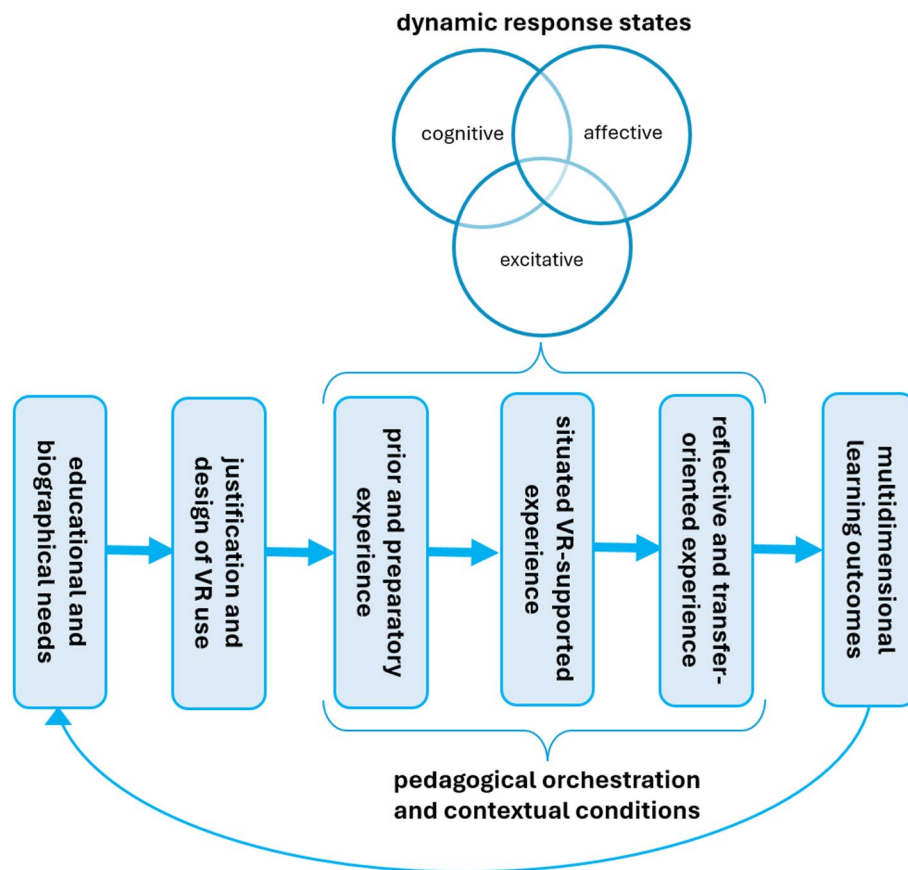
The three instructional functions, namely preparation, situated facilitation, and reflection and transfer, are connected recursively rather than through a fixed linear mechanism. Preparation influences what learners are able and inclined to notice during the virtual activity. Their situated actions and responses provide the material for subsequent reflection. Reflection may reorganize the meaning of both the virtual encounter and prior experience, while also generating knowledge, questions, orientations, or competencies that shape future activities. The contribution of the I-MEIL is therefore not the claim that preparation, facilitation, and reflection are unique to VR. Its contribution lies in specifying how these established instructional functions can be coordinated around a technologically mediated and potentially immersive episode, and how their interaction may make that episode educationally meaningful within a broader stream of experiences.

These theoretical considerations provide the basis for the structure of the I-MEIL. The model translates the three instructional functions into a sequence of interrelated analytical questions concerning the justification of VR use, the technological and representational conditions of the activity, learners' preparation, their situated experience and response states, subsequent reflection and transfer, multidimensional learning outcomes, and the emergence of further experiential needs.

### 3 The integrative model of experience-based immersive learning (I-MEIL)

The I-MEIL organizes VR-supported learning as a temporally extended and pedagogically orchestrated stream of experiences. It connects the justification and design of a VR-supported activity with learners' prior experiences, their situated engagement, subsequent reflection and transfer, and the learning outcomes that may emerge.

As illustrated in Fig. 1, the I-MEIL positions a VR-supported activity within a recursive stream of experiences. The model begins with educational and biographical needs and the question of whether and how VR use can provide an appropriate pedagogical response. The experiential process then comprises prior and preparatory experience, situated VR-supported experience, and reflective and transfer-oriented experience. These interrelated phases may contribute to multidimensional learning outcomes, which can in turn modify learners' future educational needs.



**Fig. 1** The Integrative Model of Experience-Based Immersive Learning (I-MEIL). This figure is covered by the Creative Commons Attribution 4.0 International License. Reproduced with permission of Author; copyright © Author, all rights reserved

Cognitive, affective, and excitative response states may occur and develop across the experiential process. They are conceptualized as dynamic and mutually related learner responses rather than as automatic effects of VR technology. Their emergence, intensity, and educational significance depend on the interaction of technological and representational conditions with learner interpretation and agency, instructional tasks, educator facilitation, and the wider learning context. Pedagogical orchestration and contextual conditions therefore operate across the phases of the model rather than constituting a separate intervention at a single point in time.

The arrows represent conditional and reciprocal relationships, not a deterministic causal sequence. The model does not assume that learners necessarily develop an immersive experience, engage in reflection, or achieve particular outcomes simply by participating in a VR-supported activity. Instead, it identifies analytically distinct yet interdependent components that can guide instructional design and empirical investigation. The following sections examine these components through a sequence of questions that follows the temporal and pedagogical logic of the model.

### **3.1 What educational and biographical needs may justify the use of VR?**

The starting point of the I-MEIL is not the availability of a particular technology but the identification of an educational or biographical need. An educational need refers to a discrepancy between intended learning goals and the opportunities currently available for developing the relevant knowledge, skills, or attitudes. A biographical need refers more specifically to a tension, question, limitation, or developmental challenge that emerges from learners' prior experiences and their existing relations to themselves, other people, professional practice, or the world. These categories may overlap, but they are not identical. A curricular requirement may constitute an educational need without being personally significant to every learner, whereas a biographical concern may not necessarily correspond to a formally prescribed learning objective.

The identification of such a need does not in itself justify the use of VR. It initiates a comparative design decision concerning whether a technologically mediated simulation offers relevant possibilities that cannot be achieved equally well through less complex instructional arrangements. Potentially relevant conditions include situations in which direct experience is inaccessible, dangerous, ethically problematic, costly, rare, difficult to repeat, or dependent on spatial and temporal conditions that cannot readily be reproduced. Examples include access to reconstructed historical environments [22, 50], exploration of remote or environmentally sensitive ecosystems [51, 69], and repeated practice in situations that would be risky, resource-intensive, or difficult to organize in physical settings, such as classroom management [25] or vehicle-painting procedures [49]. As a simulation technology, however, VR is not limited to reproducing situations that exist or could occur in the physical world. Its representational possibilities also allow learners to encounter constructed environments, processes, and perspectives that have no directly accessible physical equivalent [10, 47]. For example, learners may explore spatial representations of microscopic structures, manipulate abstract or otherwise non-observable phenomena, or interact with deliberately simplified models. The educational potential of simulation therefore lies both in providing controlled access to otherwise difficult experiences and in constructing representations that make particular structures, processes, or relationships available for exploration. In both cases, the relevant design question is

not whether the simulation is maximally realistic, but whether its representational and interactive properties serve the intended learning task.

The possible relevance of VR therefore lies in the relationship between learner's needs and the representational and interactive conditions of a specific VR application. Spatial representation may be useful when understanding depends on relations among objects, locations, or movements that are difficult to inspect directly. Interactive simulation may enable learners to make decisions, manipulate representations, practice procedures, and observe consequences within controlled and repeatable conditions. Sensorimotor coupling may support activities in which bodily orientation, spatial coordination, or the performance of physical actions is relevant [27, 64]. In this way, VR can provide opportunities not only to observe represented phenomena but also to act within and upon them, making learner activity itself part of the instructional task. These possibilities are not educational advantages in themselves. Their value depends on whether they are functionally aligned with the intended learning activity and whether learners can meaningfully use them.

A justification of VR should therefore address at least four questions. First, what specific educational or biographical need is being addressed? Second, which perceptual, interactive, spatial, social, or procedural requirements follow from this need? Third, what does the proposed VR application represent and allow learners to do in relation to these requirements? Fourth, does VR provide a proportionate advantage over alternative media, simulations, discussions, field experiences, role-play, video, desktop applications, or physical practice? This comparative analysis should include not only potential learning opportunities but also technical complexity, accessibility, cost, educator workload, data protection, cybersickness, and possible exclusion of learners who cannot or do not wish to use the system. The outcome of this analysis may be a decision not to use VR. In many cases, a video, interactive desktop simulation, physical model, or role-play may offer a more accessible, economical, or pedagogically appropriate response. VR should be selected only when the particular combination of representation and interaction contributes meaningfully to the intended learning design and when its additional demands can be justified. This position follows a general principle: Media should be chosen in relation to learning goals, tasks, learners, and contexts rather than on the assumption that a technologically more complex medium is inherently more effective [26].

Within the I-MEIL, educational and biographical needs therefore function as design anchors rather than as direct causes of technology adoption. They connect the intended learning process with learners' prior experiences and with a concrete educational challenge, while the subsequent justification and design phase determines whether and how VR should become part of the broader stream of experiences.

### **3.2 Which technological and representational conditions shape a VR-supported activity?**

Once the use of VR has been pedagogically justified, the technological and representational configuration of the activity must be specified. Within the I-MEIL, this configuration does not constitute the immersive experience itself. Rather, it establishes conditions under which particular forms of perception and interaction may become possible. These conditions must be selected in relation to the educational and biographical needs identified in the preceding design step.

Building on [59, 63], the I-MEIL distinguishes three broad dimensions of technological immersion: the extent and organization of sensory information, the degree to which users can control their perceptual position, and the extent to which they can modify the virtual environment and its objects. These dimensions can be further described through fidelity, interactivity, sensorimotor contingency, and multisensory representation. They are analytically separable but often interdependent in a concrete application.

*Fidelity* concerns the extent to which the virtual environment provides coherent and functionally relevant representations of objects, spaces, processes, or situations. It should not be equated with visual realism alone. A highly realistic representation may be unnecessary or even distracting when schematic or simplified information better supports the intended task. Conversely, detailed spatial or procedural representation may be important when learners need to distinguish subtle features, navigate complex environments, or coordinate actions with physical structures [10]. The relevant question is therefore not how realistic an environment appears in general, but which representational features must be sufficiently accurate, stable, and intelligible for the intended learning activity.

*Interactivity* refers to the range of actions available to learners and to the extent to which these actions produce meaningful and timely system responses. Learners may observe, navigate, select, manipulate, communicate, make decisions, or practice procedures. However, a greater number of interaction possibilities does not necessarily improve learning. Interactions are relevant only when they correspond to the intended task and make consequential relations visible. Decorative or poorly aligned interactions may divide attention or increase cognitive demands. The design of interactivity must therefore specify not only what learners can do, but why these actions matter for the learning process.

*Sensorimotor contingency* describes the correspondence between learners' movements and changes in the virtual environment. Head tracking, body tracking, hand controllers, or camera-based hand tracking can enable the system to respond to physical movement in real time [56, 76]. Such correspondence may be important for spatial orientation, procedural practice, or the perception of control. Nevertheless, sensorimotor responsiveness should not be interpreted as evidence that learners experience agency or embodiment. Inaccurate tracking, delayed feedback, restricted movement, or discrepancies between physical and virtual action may reduce usability, disrupt the experience, or contribute to discomfort.

*Multisensory representation* concerns the integration of visual and auditory information with possible haptic, tactile, olfactory, or other sensory feedback. Recent VR applications increasingly extend beyond visual and auditory presentation through devices that simulate touch, resistance, texture, movement, or smell [7, 60, 68]. Such information can be useful when a learning task depends on sensory discrimination, spatial orientation, manual coordination, or the recognition of environmental conditions. Multisensory presentation is not inherently beneficial, however. Additional sensory information may be irrelevant, distracting, inaccessible to some learners, or difficult to integrate with the primary task. Its inclusion should therefore be justified by a clear instructional function.

The technological configuration also determines practical and ethical conditions of participation. Device weight, display quality, interaction complexity, physical space,

accessibility, hygiene, data collection, and the risk of cybersickness can shape whether learners are able and willing to participate [66]. These conditions may affect learners differently according to prior VR experience, sensory or motor abilities, and health-related constraints. Designers should therefore provide alternatives, opportunities to interrupt participation, and forms of support that do not disadvantage learners who cannot or prefer not to use a particular system.

Representational design requires equal attention. Every virtual environment selects, simplifies, organizes, and frames aspects of a situation. It provides some perspectives and possibilities for action while excluding others. These decisions are especially consequential when applications represent historical events, social conflict, culturally specific contexts, or experiences of marginalized groups. A first-person visual position, an avatar, or a simulated role does not provide direct access to another person's identity or lived experience. Such representations should be treated as constructed perspectives whose assumptions, omissions, and limitations require explicit pedagogical contextualization [34].

Fidelity, interactivity, sensorimotor contingency, and multisensory representation therefore function as design variables whose relevance depends on their alignment with the intended task, content, learners, and context. The central design question is whether a particular technological and representational configuration enables appropriate forms of perception and action without creating unnecessary barriers or competing demands.

### **3.3 How can learners be prepared for a VR-supported experience?**

Preparation connects learners' prior experiences with the technological, conceptual, and instructional demands of the forthcoming VR-supported activity. Within the I-MEIL, preparation is not a standardized preliminary step but a design function whose form depends on the intended learning goals, represented content, technological configuration, and learners' prior knowledge. Its purpose is to create conditions that may support orientation and informed participation without predetermining how learners will interpret or respond to the virtual environment.

A first function of preparation is to activate and, where necessary, develop the knowledge required to engage meaningfully with the task. Learners may need conceptual terminology, procedural schemas, historical or social background knowledge, or criteria for interpreting what they will encounter. Advance organizers, conceptual summaries, short diagnostic activities, pre-training, worked examples, or guiding questions can help learners identify relevant structures and reduce the need to process unfamiliar content and interaction demands simultaneously [30, 44, 45]. However, the amount and form of preparation should be calibrated carefully. Excessive explanation may reduce opportunities for exploration or bias learners toward a single interpretation, whereas insufficient preparation may leave them unable to distinguish instructionally relevant information from salient but peripheral details.

A second function concerns task orientation. Learners should understand what they are expected to observe, investigate, decide, practice, or compare during the VR-supported activity. Such orientation may include explicit learning goals, procedural instructions, observation criteria, or decision prompts. The task should focus attention without reducing the virtual activity to the mechanical completion of instructions. Especially in open or exploratory environments, preparation can clarify the purpose of interaction

and establish connections between the virtual activity and the broader instructional sequence [71].

Technical familiarization constitutes a third preparatory function. Unfamiliar interaction techniques can compete with content processing and may lead learners to attribute difficulties to themselves or to the learning content rather than to the interface. Tutorials, orientation tasks, or short practice scenarios can therefore introduce locomotion, object manipulation, menu navigation, controller use, and safety procedures before the main activity begins [33]. Such familiarization may take place outside VR through demonstrations or videos, or within the virtual environment through a separate low-stakes orientation phase. It should be sufficiently distinct from the primary learning task so that technical errors do not obscure disciplinary performance. Technical familiarization also prepares learners to make use of experiential conditions such as agency and embodiment without making these states prerequisites for learning. Learners need to understand how their movements and actions correspond to system responses, how objects can be manipulated, and, where applicable, how their physical actions relate to a represented virtual body. Such familiarization may reduce attention directed toward operating the interface and thereby facilitate greater focus on the instructional task [46]. Preparation, however, should not aim to induce presence or embodiment as outcomes in themselves, but to establish sufficiently transparent interaction conditions for learners to engage with task-relevant features of the virtual environment. At the same time, instructional activities should remain meaningful when learners experience only limited presence or embodiment, as these subjective states vary between learners and situations.

Preparation also includes physical and regulatory orientation. Learners should receive information about the physical space, possible discomfort, cybersickness, procedures for pausing or terminating participation, and available alternative formats. They should be encouraged to report discomfort without experiencing this as failure or noncompliance. This is particularly important because willingness and physical tolerance cannot be assumed from the mere availability of the technology [66, 71].

Preparation can also address learners' expectations and affective readiness. Goal clarification, narrative framing, or opportunities to articulate concerns may help learners anticipate the activity and regulate uncertainty [36]. However, affective preparation should not be understood as an attempt to produce a desired emotional state. Learners may respond with interest, indifference, discomfort, resistance, or other reactions that cannot and should not be fully controlled through instructional design. The role of preparation is to support informed engagement and psychological safety rather than to prescribe how learners ought to feel.

Preparatory activities may occur both outside and inside VR. Outside-VR preparation can support conceptual discussion, diagnostic assessment, and access to supplementary materials. In-VR preparation can familiarize learners with the spatial arrangement and interaction logic of the system. The choice between these formats should depend on the function of the activity. Conceptual or critical framing may be easier to conduct in a socially accessible setting outside the headset, whereas technical orientation may benefit from direct practice within the system [71].

Within the I-MEIL, preparation is conceptualized as the first pedagogically orchestrated phase of the stream of experiences. It links learners' prior knowledge and biographical orientations with the technological and instructional conditions of the situated

VR-supported activity and provides conceptual, technical, and regulatory resources for participation.

### 3.4 How can situated immersive experience be conceptualized?

Within the I-MEIL, situated immersive experience refers to learners' subjective and temporally variable responses while interacting with a VR-supported environment. Learners may become absorbed in particular moments, attend selectively, experience technical or physical disruption, or interpret the same virtual situation in different ways [52]. Situated immersive experience is therefore conceptualized as a potentially discontinuous process shaped by technological and representational conditions, task design, learner characteristics, educator facilitation, and context.

To describe the processes involved, the I-MEIL draws on the Differential Susceptibility to Media Effects Model [72]. The DSMM distinguishes three analytically separable but potentially interacting response states. *Cognitive response states* concern attention, interpretation, mental effort, and the processing of represented information. *Affective response states* comprise valenced reactions such as interest, curiosity, enjoyment, discomfort, compassion, or frustration. *Excitatory response states* refer to physiological activation and arousal. These states are transient rather than stable learner attributes and may fluctuate before, during, and after the VR-supported activity.

Specific representational and interactive characteristics of VR may contribute to these response states in different ways. Novel or perceptually salient features may initially attract attention and encourage exploration, but novelty can also direct cognitive resources toward the technology itself rather than toward instructionally relevant content [32, 46]. Likewise, opportunities to explore, manipulate, or act within a simulated environment may be associated with interest, enjoyment, and motivational responses, which should be distinguished from learning outcomes themselves. Such responses become educationally relevant when they orient attention toward task-relevant information, sustain engagement with demanding activities, or encourage productive exploration and further processing. Conversely, heightened arousal, novelty, or perceptual salience may compete with learning-related processing when attention is directed toward instructionally irrelevant features. The educational significance of these response states therefore depends not simply on their intensity, but on how they relate to the content and demands of the instructional task.

Beyond novelty, the response states can be related more specifically to what learners perceive and do within a VR-supported activity. Representational features can direct cognitive responses by making spatial relations, changes over time, or otherwise difficult-to-observe processes available for inspection. Interactive features can couple learners' decisions and actions with visible consequences, thereby providing information for interpretation, comparison, and adjustment. The content and framing of a simulation may elicit affective responses when learners appraise represented events as relevant, unexpected, challenging, or personally meaningful. Excitatory responses may arise from perceptual intensity, movement, time pressure, uncertainty, or other activating features of the situation. Importantly, these responses can occur simultaneously and influence how learners engage with the task. For example, an unexpected event may increase physiological activation, attract attention, and be appraised as interesting or threatening, with different implications for subsequent processing and action. The three response states

should therefore not be understood as a fixed causal chain but as dynamically interacting processes. Physiological activation may orient attention or produce discomfort, affective appraisal may direct learners toward or away from particular aspects of a situation, and cognitive appraisal may in turn modify these responses. Their educational significance depends on their object, intensity, duration, and relationship with the instructional task rather than on the strength of activation alone.

Constructs frequently examined in VR research can provide indicators of particular aspects of situated experience, but they should not be treated as interchangeable or as complete representations of the three response states. *Presence* describes the subjective sense of being located in or responding to the mediated environment rather than merely observing it [37, 67]. It can vary across physical, social, and self-related dimensions [31]. For learning, presence may become relevant when the perceived immediacy of the simulated environment supports sustained attention to task-relevant events, situated interaction, or the interpretation of spatial and contextual relations [40]. Its educational function therefore depends on what learners attend to and do within the environment. A strong sense of presence does not itself demonstrate conceptual understanding or learning and may coexist with high cognitive demands [41]. Perceived *agency* and *embodiment* describe different aspects of learners' relation to action and the represented body. Perceived agency concerns the subjective sense of initiating and controlling actions and their consequences [48]. For learning, agency may become relevant when learners can intentionally manipulate objects, make decisions, test actions, and observe task-relevant consequences, thereby connecting their own activity with the structure of the simulated task [40]. Embodiment, in contrast, concerns the experience of having, controlling, or being spatially located within a virtual body [1, 35]. Its educational relevance is particularly plausible when bodily action itself carries task-relevant information, for example when spatial orientation, coordinated movement, object manipulation, or procedural performance forms part of what is to be learned. In such cases, congruence between bodily action and the represented task may provide an additional sensorimotor basis for processing and practice [35]. Agency and embodiment thus become educationally relevant not because control or virtual body representation is inherently beneficial, but when learners' actions are functionally related to the intended learning process. Both depend partly on the correspondence between learners' movements and system feedback, but neither follows automatically from available interaction or avatar representation. Importantly, embodiment should not be interpreted as becoming another person or gaining access to that person's identity. It remains a technologically mediated and individually interpreted bodily experience. *Cognitive load* concerns the demands placed on limited working-memory resources during the activity [6, 70]. In VR-supported learning, such demands can arise from the instructional content, the task, interface operation, navigation, sensory complexity, or the coordination of physical and virtual action. Signaling and other forms of guidance may help learners focus on relevant information, whereas poorly aligned interactions may create extraneous processing demands [39, 73].

Taken together, cognitive, affective, and excitative response states provide a parsimonious framework for examining learners' situated responses. Presence, perceived agency, embodiment, and cognitive load offer empirical indicators of selected aspects of this experience, whose relevance should be determined in relation to the instructional

design. However, these transient responses can subsequently become objects of interpretation and reflection.

### 3.5 How can reflection and transfer be supported after a VR-supported experience?

Reflection and transfer constitute the third experiential phase of the I-MEIL. Their function is to provide opportunities for learners to articulate, examine, and reorganize what they perceived, felt, thought, and did during the VR-supported activity. The form and depth of reflection should depend on the intended learning outcomes, represented content, task, and responses that emerged during the situated experience.

Dewey's conception of reflective thought provides a central theoretical foundation for this phase. For Dewey [14], an experience becomes meaningful through its reconstruction in relation to prior and subsequent experience. Reflection can help learners identify relations, question initial interpretations, and connect a particular encounter with broader concepts and possible courses of action. Within the I-MEIL, this means that the significance of a VR-supported episode may remain limited when learners are not given opportunities to contextualize and integrate what occurred.

Kolb's [29] experiential learning cycle further specifies the relationship between experience, reflection, conceptualization, and subsequent action. A concrete experience may provide material for reflective observation, reflection may support the development or revision of abstract concepts, and these concepts may inform active experimentation in later situations. VR-supported activities can provide forms of concrete and situated experience, but they do not complete the experiential learning cycle by themselves. The I-MEIL adopts this cyclical logic while rejecting the assumption that all learners necessarily progress through the phases in the same order or with the same depth.

Generative learning theory helps clarify the cognitive activities through which reflection may support integration. Activities such as self-explaining require learners to select relevant information, organize it into a coherent structure, and connect it with existing knowledge [15, 44]. For VR-supported experiences, reflection can additionally help learners distinguish the immediacy of the simulated experience from the meaning that should be derived from it. A strong sense of presence, agency, or embodiment may make particular events or actions salient and memorable, but these experiential qualities do not determine what learners understand from them. Reflective activities can therefore redirect attention from the experience itself toward its task-relevant features, underlying principles, consequences of learners' actions, and connections to prior knowledge or future situations. In this way, experiential states become potential resources for subsequent meaning-making rather than learning outcomes in themselves.

In VR-supported learning, such activities can be implemented through guided debriefings, written reflections, concept maps, collaborative discussions, comparison with additional sources, or the application of insights to a new case. Their effectiveness depends on their alignment with the learning goal and on whether they help learners process relevant aspects of the experience rather than merely reproduce memorable details [71]. Post-VR reflection may therefore address several related but analytically distinct objects. First, learners may reflect on the represented content, including concepts, events, procedures, decisions, or social relations encountered in the virtual environment. Second, they may examine their own actions and responses, such as moments of uncertainty, emotional involvement, perceived control, cognitive overload, or disengagement. Third,

they may critically consider the technological mediation itself: How avatar design, narrative structure, interaction possibilities, feedback, and sensory salience influenced what they noticed and how they interpreted the situation. Fourth, they may examine the limits of the representation, including omitted perspectives, simplifications, assumptions, and discrepancies between the simulation and the contexts it represents.

Transfer extends reflection beyond the reconstruction of the completed activity. Depending on the intended outcomes, learners may apply conceptual understanding to a new problem, practice a procedure in a different setting, compare the simulation with a real case, or formulate criteria for future decisions. Transfer should not be assumed from performance within the virtual environment because success under simulated conditions may depend on prompts, feedback, representations, or interaction patterns that are absent elsewhere. Tasks designed for variation, comparison, explanation, and application can help educators examine whether learning extends beyond the original virtual episode.

Reflection and transfer may take place individually or socially. Individual formats can provide time for personal organization and elaboration, whereas educator-guided or collaborative formats can expose learners to alternative interpretations, disciplinary knowledge, and critical questions. Because learning is socially and institutionally situated, educator facilitation remains particularly important when learners' interpretations are incomplete, ethically problematic, or based on misconceptions. Facilitation should nevertheless support inquiry rather than impose a predetermined personal response.

Within the I-MEIL, reflection and transfer function as bridges between the situated experience and multidimensional learning outcomes. They support the reconstruction, contextualization, consolidation, and application of an experience and may confirm existing orientations, extend knowledge and competencies, expose unresolved tensions, or generate new educational and biographical needs. In this way, reflection and transfer reconnect the virtual episode with the wider biographical stream of experiences.

### **3.6 Which multidimensional learning outcomes may emerge from VR-supported learning?**

The I-MEIL conceptualizes learning outcomes as multidimensional and distinguishes them from the transient response states according to [72]. Cognitive, affective, and excitative response states describe situational processes such as presence. Learning outcomes, by contrast, refer to comparatively more enduring changes in knowledge, understanding, skills, attitudes, dispositions, or behavior that extend beyond the immediate experience. Empirical claims about learning should therefore rely on measures aligned with these intended outcomes rather than on indicators of transient experience alone.

Existing models of immersive learning have contributed substantially to explaining cognitive and affective processes associated with VR use, but empirical research continues to focus predominantly on knowledge acquisition and procedural performance [13, 40, 58, 61]. The I-MEIL broadens this perspective by distinguishing five potential outcome domains: cognitive, affective, attitudinal, behavioral, and psychomotor outcomes.

*Cognitive outcomes* include changes in declarative, conceptual, or procedural knowledge and in learners' ability to understand, explain, or apply relationships. VR-supported activities may support learning through active exploration, situated cognition, and contextualized understanding [13, 40]. *Affective outcomes* refer to changes in learners'

emotional understanding, emotional awareness, or capacity to recognize, differentiate, and regulate affective responses in relation to a learning object. They should not be equated with the immediate experience of enjoyment, sadness, fear, or compassion during VR use. A transient emotion becomes relevant only when it contributes to a more enduring capacity for interpretation, appraisal, or regulation [36]. *Attitudinal outcomes* concern relatively enduring evaluations of persons, groups, practices, issues, or concepts [55]. VR-supported activities may be designed to challenge assumptions or invite reconsideration of an issue [51, 69], but attitude change cannot be inferred from emotional intensity or from taking a particular visual perspective. It must be examined through validated measures and, where relevant, across more than one measurement point. *Behavioral outcomes* refer to observable actions or choices that occur beyond the immediate demands of the virtual activity. These may include subsequent decision-making, participation, prosocial action, environmentally responsible conduct, or the application of learned strategies in another context [16, 65]. Behavioral intentions and self-reports should be distinguished from actual behavior. Likewise, behavior performed within a simulation should not automatically be treated as evidence of transfer. Where behavioral outcomes are intended, research should examine whether actions generalize beyond the original virtual setting and persist over time. *Psychomotor outcomes* concern the development of coordinated perceptual and motor skills through practice. VR-supported simulation may be particularly relevant for procedures that are hazardous, expensive, rare, or difficult to repeat in physical settings, such as welding, emergency response, or complex technical operation [23, 49, 58]. However, performance within VR may depend on tracking systems, controllers, feedback, or simplified task conditions that differ from real-world practice.

The five outcome domains should not be treated as a mandatory checklist. A given learning design may legitimately target only one or two domains. Their inclusion in the I-MEIL serves to prevent learning from being reduced to knowledge acquisition and to encourage alignment among educational needs, instructional tasks, experiential processes, and outcome measures. Claims about learning should be based on indicators that correspond to the intended outcome domain and should remain separate from measures of technological immersion or subjective experience.

The relationships among outcome domains are also conditional. For example, although attitudes do not directly determine behavior, attitudinal change is often a prerequisite for behavioral change [17]. However, such relationships should be theoretically specified and empirically tested rather than assumed. The I-MEIL therefore treats multidimensional outcomes as potentially related but analytically distinguishable consequences of the broader experiential and instructional process.

### 3.7 How do learning outcomes reshape future educational and biographical needs?

The final component of the I-MEIL reconnects learning outcomes with the emergence of future educational and biographical needs. Learning outcomes are therefore not treated as the endpoint of a closed instructional sequence. New knowledge, skills, attitudes, or forms of understanding may alter how learners perceive subsequent situations, identify unresolved questions, or recognize limitations in their existing competencies.

This recursive logic follows Dewey's principle of continuity, according to which every experience influences the conditions under which later experiences are interpreted [14].

It is also compatible with Kolb's [29] cyclical account of experiential learning, in which conceptual understanding and active experimentation generate new concrete experiences. Learning may confirm existing orientations, produce partial change, expose contradictions, or leave important needs unresolved.

The outcomes of a VR-supported learning sequence may therefore become resources or challenges for subsequent learning. Cognitive understanding may generate more advanced questions, psychomotor competence may reveal the need for practice under less supported conditions, attitudinal development may prompt reconsideration of future action, and reflection may make learners aware of assumptions or limitations that were previously unnoticed. Conversely, unsuccessful, confusing, or problematic experiences may also create new needs for clarification, corrective instruction, emotional support, or alternative learning opportunities.

The emergence of a new need does not imply that VR should be used again. As at the beginning of the model, the appropriate educational response must be determined by the goals, learners, content, and context. A subsequent activity may involve discussion, direct practice, reading, video, another form of simulation, or no additional intervention. VR remains one possible medium within a broader pedagogical repertoire. The recursive structure of the I-MEIL thus expresses the continuity of educational experience rather than a cycle of repeated technology use.

## **4 Implications for future research and instructional design**

### **4.1 Implications for future research**

The I-MEIL provides a framework for examining VR-supported learning as a temporally extended and pedagogically situated process rather than as an effect of technology alone. Its primary empirical implication is that research should distinguish technological conditions, subjective response states, instructional processes, and learning outcomes. Measures of presence, agency, embodiment, or cognitive load should not be interpreted as evidence of learning unless they are connected with corresponding outcome measures. Likewise, comparisons between VR and another medium cannot by themselves explain why differences occur unless the technological, representational, task-related, and pedagogical conditions of the interventions are specified.

Future research should therefore examine relationships across the three experiential phases. Studies may investigate (1) how prior knowledge, expectations, technical familiarity, and instructional preparation influence learners' situated responses, (2) how task design, educator facilitation, and technological configuration shape attention, interpretation, and action during the virtual activity, and (3) how different forms of reflection and transfer support the consolidation or reconstruction of experience. Longitudinal and process-oriented designs are particularly important because the I-MEIL assumes that the educational meaning of a VR-supported activity may emerge across time rather than during the virtual episode alone.

The constructs of the model require differentiated operationalization. Technological immersion can be documented through system characteristics such as display configuration, tracking, field of view, interaction possibilities, sensory channels, and response latency. Representational conditions should be described in terms of content, perspective, realism or abstraction, narrative structure, available actions, feedback, and omitted or simplified aspects of the represented situation. Such documentation is necessary to

enable meaningful comparison across applications and to avoid treating all uses of VR as equivalent interventions.

Cognitive, affective, and excitative response states also require distinct measurement strategies. Cognitive responses may be examined through attention measures, verbal protocols, interaction data, or cognitive-load instruments. Affective responses may be studied through state-specific self-reports, appraisal measures, qualitative accounts, or observational data. Excitative responses may be assessed through physiological indicators such as electrodermal activity, heart-rate variability, or pupillometry, provided that such data are interpreted cautiously and in relation to the task and context [2, 4, 62]. Triangulation is especially valuable because no single indicator reveals how learners perceived, interpreted, and integrated the virtual activity.

Measures should also distinguish transient response states from learning outcomes. For example, the PANAS can capture current positive and negative affective states, but it does not by itself demonstrate affective learning [74]. Similarly, the Interpersonal Reactivity Index assesses dispositional dimensions related to empathy and perspective-taking rather than providing direct evidence that a particular VR activity produced understanding of another person's experience [11]. Outcome measures should therefore correspond to the intended domain and include knowledge tests, transfer tasks, performance assessments, validated attitude measures, observed behavior, or psychomotor performance where appropriate.

Research on preparation should compare not only the presence or absence of preparatory activities but also their function, timing, and alignment. Relevant contrasts may include conceptual pre-training, task orientation, technical familiarization, critical contextualization, or combinations of these elements. Studies should also examine whether preparation reduces interface-related demands, supports attention to instructionally relevant information, or inadvertently constrains exploration and interpretation. Learners' prior VR experience, prior knowledge, accessibility needs, and susceptibility to cybersickness should be considered as potential moderators.

Research on reflection and transfer should similarly distinguish among formats and functions. Guided debriefing, collaborative discussion, written reflection, concept mapping, and subsequent application tasks may support different forms of processing. Their effects should not be assumed to generalize across cognitive, affective, attitudinal, behavioral, and psychomotor outcomes. Delgado and Mayer [12], for example, demonstrate that a generative learning strategy that is effective in other contexts may not yield additional benefits in procedural immersive learning and may introduce competing demands. Future studies should therefore examine when, for whom, and under which task conditions reflective or generative activities are beneficial.

The recursive logic of the I-MEIL further suggests the value of delayed and longitudinal measurement. Immediate post-tests may capture short-term effects but provide limited evidence concerning transfer, attitude stability, behavioral change, or the emergence of new educational and biographical needs. Follow-up assessments, repeated observations, and analysis of subsequent learning activities can help determine whether and how a VR-supported experience becomes integrated into learners' broader development.

Finally, empirical work should test the I-MEIL as a set of conditional relationships rather than as one monolithic model that must be validated in a single study. Individual studies may examine selected pathways, such as the relationship between technical

**Table 1** Empirical operationalization of selected I-MEIL components

| I-MEIL component                            | Example indicators                                                 | Typical instruments                                                       | Possible research designs                          |
|---------------------------------------------|--------------------------------------------------------------------|---------------------------------------------------------------------------|----------------------------------------------------|
| Prior and preparatory experience            | Goal clarity, expectancy, motivation                               | Expectancy and motivation measures [75], prior knowledge                  | Randomized studies (with vs. without pre-briefing) |
| Affective response states                   | Interest, compassion, curiosity                                    | PANAS [74]                                                                | Post-immersion surveys, in-VR affect tracking      |
| Excitative VR-supported experience          | Physiological arousal intensity                                    | Electrodermal activity [4], heart-rate variability [62], pupillometry [2] | Real-time physiological logging during immersion   |
| Cognitive VR-supported experience           | Attention, cognitive load                                          | Cognitive load measures (e.g., NASA-TLX; [21]); eye-tracking [24]         | Laboratory or field experiments                    |
| Reflective and transfer-oriented experience | Depth of elaboration, integration of meaning                       | Concept maps [54]                                                         | Randomized studies (with vs. without debriefing)   |
| Learning outcomes                           | Cognitive, affective, attitudinal, behavioral, psychomotor changes | Knowledge tests, attitude scales, performance tests                       | Longitudinal or experimental studies               |

familiarization and cognitive load, between task design and perceived agency, or between critical reflection and transfer. Accumulating evidence across different contexts, learner groups, contents, and outcome domains can progressively refine the boundaries and explanatory value of the framework.

Table 1 summarizes selected constructs of the I-MEIL, possible indicators and measurement approaches, and research designs suited to examine relationships across the stream of experiences. The examples are illustrative rather than exhaustive, and the appropriateness of each measure depends on the specific construct, task, learner group, and research question.

#### 4.2 Implications for instructional design

For instructional design, the I-MEIL offers a sequence of questions rather than a universal prescription for using VR. The first question concerns whether a clearly defined educational or biographical need exists and whether VR provides a proportionate response to that need. Designers should compare VR with alternative media and learning arrangements and select it only when its particular representational and interactive conditions contribute meaningfully to the intended activity.

When VR is selected, technological and representational decisions should be derived from the learning task rather than from a general preference for greater realism, interactivity, or sensory richness. Fidelity should be functional, interaction should make instructionally relevant relations actionable, and multisensory information should be included only when it supports perception, orientation, discrimination, or coordinated action. Additional features that are salient but unrelated to the learning goal may increase distraction, technical complexity, or accessibility barriers.

Preparation should address the specific demands of the activity. Conceptual preparation can provide necessary background knowledge and interpretive criteria, task orientation can clarify what learners are expected to observe, decide, practice, or compare, and technical familiarization can reduce interface-related demands. Designers should also communicate procedures for interruption, alternative participation, and possible

discomfort or cybersickness. In ethically sensitive applications, preparation should make the constructed and selective nature of the representation explicit.

During the VR-supported activity, task design should provide a clear relationship between learner action and educational purpose. Interaction should not be included merely to increase activity. Learners should be able to understand why a decision, manipulation, movement, or observation matters for the task. Scaffolds and feedback should support orientation while avoiding unnecessary interruption or over-direction. Depending on the setting, educators may observe, provide assistance, facilitate collaboration, or intervene when technical difficulties, misconceptions, distress, or unsafe behavior arise. Learner agency should be preserved across all phases. This includes the possibility of interpreting the virtual representation differently from its intended message, declining particular forms of participation, interrupting the activity, or using alternative formats.

Reflection should be aligned with both the intended outcomes and the specific features of the preceding activity. A conceptual learning task may require explanation, comparison, or application, procedural practice may require error analysis and performance review, and socially sensitive representations may require critical contextualization and examination of omitted perspectives. Transfer activities should move beyond recall of the virtual episode. Learners may apply knowledge to a new case, perform a procedure under changed conditions, compare the simulation with external evidence, justify a decision, or develop criteria for future action. Where transfer to real-world performance is intended, designers should progressively reduce VR-specific support and provide opportunities to practice in authentic or differently mediated contexts.

The model also directs attention to inclusion and sustainability. Access to hardware, physical space, technical support, time, educator expertise, data protection, hygiene, and accessibility should be considered alongside pedagogical opportunities. Learners who cannot or do not wish to use a head-mounted display should not be excluded from achieving the intended learning goals. Alternative formats should therefore be treated as part of the design rather than as improvised exceptions.

Taken together, these principles position VR as one component within a broader instructional arrangement. The quality of a VR-supported learning design depends less on the technological intensity of the virtual episode than on the coherence among educational needs, learner characteristics, representation, task design, facilitation, preparation, reflection, transfer, and assessment.

## 5 Conclusion

The I-MEIL conceptualizes VR-supported learning as a temporally extended and pedagogically orchestrated stream of experiences. Its central premise is that neither the technological properties of VR nor the subjective intensity of a virtual encounter are sufficient to explain learning. Educational significance emerges conditionally through the relationship among learners' prior experiences, the justification and design of VR use, situated engagement, task demands, educator facilitation, reflection, transfer, and the instructional context.

By distinguishing technological immersion, subjective immersive experience, and immersive learning, the model avoids equating headset use with presence, engagement, or learning. It further differentiates transient cognitive, affective, and excitative response

states from multidimensional learning outcomes. Presence, embodiment, agency, cognitive load, and physiological activation may characterize aspects of learners' situated experience, but they do not in themselves demonstrate cognitive, affective, attitudinal, behavioral, or psychomotor learning.

The contribution of the I-MEIL lies particularly in extending analysis beyond the virtual episode. Preparation provides conceptual, technical, and critical orientation. Task design and educator facilitation structure opportunities for perception and action, and reflection and transfer connect situated experience with subsequent conceptualization, practice, and development. The framework thereby specifies how these instructional functions can be coordinated around a VR-supported activity rather than treating the virtual episode as an isolated intervention.

The model also positions VR as one possible medium within a broader pedagogical repertoire. Its use should be justified by a specific educational or biographical need and by a functional relationship between the intended task and the technological and representational conditions of a particular application. In some cases, VR may provide valuable opportunities for spatial exploration, procedural practice, simulation, or access to otherwise difficult situations. In others, less complex or more accessible instructional formats may be equally or more appropriate.

For research, the I-MEIL offers a structure for examining conditional relationships across phases rather than attributing outcomes to VR as a uniform intervention. Future studies can investigate selected pathways among preparation, technological and representational conditions, response states, reflection, transfer, and multidimensional outcomes. In this way, the framework provides both a design-oriented vocabulary and an empirically examinable architecture for understanding how a VR-supported activity may become educationally meaningful within learners' continuing stream of experiences.

#### **Author contributions**

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##### **Consent for publication**

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##### **Competing interests**

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