Prototype Design of XR technology for psychomotor skill learning (PSL): Layering content focus and feedback to prompt deep PSL

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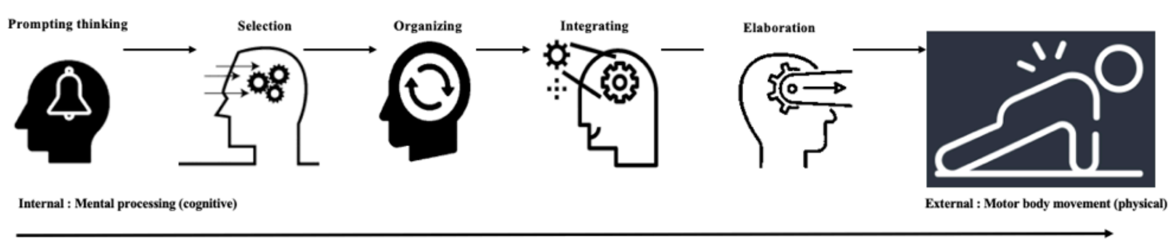
Contemporary research in the realm of psychomotor skill learning uses sophisticated features of Extended reality (XR) technologies (VR/AR/MR), with promising implications towards accelerating learning process and enhancing learning outcome. A functional prototype is presented that replicates the potential representation of underlying PSL mechanism including both mental processing and motor movements. Rather than focusing on immersing learners in the virtual environment, this prototype aims at reversely immersing them in the intricate mechanisms of psychomotor skill to achieve deeper levels of PSL. The proposed prototype challenges the traditional emphasis on observable behaviors, informing the significant role of mental processing. The integration of mental and motor processing enables learners to completely immerse themselves in the psychomotor task leading to more effective and efficient PSL. Learners engaged in psychomotor tasks use external sensory stimuli to promptly refine their body movements for optimal performance. This paper contributes to PSL discourse offering practical insights and implications.

Psychomotor skills learning

Psychomotor skills learning (PSL), gross and fine physical behaviors with or without tools, involves the hierarchical development of skills through mental and motor processing (Miller et al., 1960), indicative of the path towards mastery (Romiszowski, 1999). Dave (1970) proposed that skills are developed in progressive levels encompassing imitation, manipulation, precision, articulation, and naturalization. Although skill development has been studied from multiple perspectives, the underlying mechanisms of PSL phenomenon remain not entirely comprehended. Additionally, the rapid rise of emerging technologies has led to the expansive uses of Virtual, Augmented, and other forms of Extended Reality for simulating skills training. Many examples can be found in sports (Pagé et al., 2019), healthcare (Stanney et al., 2022), and music education (Chen, 2022). Given the complexity of underlying PSL mechanisms and the rapid development of XR technologies, it is questionable as to whether features of emerging technologies have been used most effectively to support PSL - has the use of emerging technologies gone beyond the traditional skills training methods of modeling and practice? While researchers have focused on overt behaviors (physical body movement), they have often provided less emphasis on the mental processing necessary to achieve deeper levels of PSL (Singer, 1978).

Figure 1

Four Elements of Generative Learning (Selecting, Organizing, Integrating and Elaboration)



A prototype XR instructional intervention aims to enhance PSL process by completely immersing learners in both mental and motor processing during PSL. This prototype conveys central tenets that learners are not focused on the immersive virtual environment - learning from the technology; rather, learners are immersed in the PSL task while using technology features to scaffold their PSL processes - learning with the technology (Jonassen, 2013). Despite numerous empirical studies on PSL with XR technology, several instructional interventions are observed to lack features that prompt thinking while providing consistent feedback on the accuracy or correctness of the skill during the learning process. These studies often produced learning outcomes at a surface level, lacking the mental skills necessary to achieve higher efficiency. Seamlessly integrating both mental and motor processing into PSL facilitates the progression of skills from imitation to naturalization, incorporating layers of feedback in instruction. The prototype design developed incorporating three theoretical frameworks, generative learning, cognitive flexibility, and reflection principles (Figure 1), illustrates how sophisticated features of XR technology can prompt thinking while reinforcing the hierarchical development of skills. Issues concerning learner focus on psychomotor tasks, technology, environment, and implications of the proposed prototype are discussed.

Psychomotor skill learning with XR technology

Has the focus of PSL with emerging technologies been effective in immersing learners in progressive PSL? For several decades, one prominent aspect studied in PSL has centered on investigating the influence of intervention on both efficacy denoting the "ability to bring about some end result with maximum certainty" (Guthrie 1952, p. 136) and efficiency, characterized as the "minimum outlay of energy or of time and energy" (Guthrie, 1952, p. 136). Little has been studied on how to prompt the mental processes involved in PSL. Psychomotor skills are developed with physical movement connected to conscious mental processing (Oermann, 1990). Previous studies focused on providing models of expected behaviors to encourage PSL and failed to engage learners in associated mental processes. It was assumed that simply supporting learners with models encouraged them to engage in multimodal processing that helped them create awareness of knowledge gaps and correct misconceptions about their physical behaviors (Sigrist et al., 2013).

Unpacking these underlying mechanisms of how psychomotor skills are learned may help influence learning and performance during instruction (Wulf, 2013). Duffy and Jonassen (1992) suggested that technology may aid knowledge construction by helping learners interpret, integrate, and organize the new information and episodes encountered through experiences into existing mental structures by employing essential cognitive prompts. These tenets are mirrored in principles of generative learning (GLT) and cognitive flexibility (CFT) theories (Koszalka et al., 2019). Best practices in PSL suggest that sequence - simple-to-complex and order - most essential information in detail prior to complex information is warranted (Jonassen et al., 2013). GLT advocates that learners be physically active and aware of their internal mental process in its entirety (Wittrock, 1992) during PSL processes (Ainsworth & Loizou, 2003). Cratty (1967) also suggested the need to prompt learners to think about the skill task, performance, environment, and other internal factors associated with PSL. Without fully immersing learners in PSL tasks, the learner does not begin to construct meaning of new incoming information about the skill (Wittrock, 1992). The quality of mental processing and motor movement impacts the ultimate level of learning, performance, and proficiency of the skill (Singer, 2002). As learners immerse in the PSL task and use emerging technologies, they begin to learn with technological support rather than just how to replicate movements (Jonassen et al., 2013).

Rapid advancements in emerging technologies are impacting PSL training. Although a plethora of technology tools (VR/AR/MR) are available in the market to guide PSL training, these tools do not take advantage of existing features that can deeply engage learners in PSL mental processing, nor do they always offer scaffolding to provide consistent feedback that may aid in progressively developing specific skills. How can these emerging technologies and their sophisticated features be designed into instructional tools (Gagne & Briggs, 1974) that do not merely immerse learners in a virtual environment (i.e., immersive VR/AR/MR), but rather, become scaffolds to immerse the learner in the PSL task via mental and motor processing (i.e., reverse-immersive VR/AR/MR)? In other words, as suggested by Jonassen et al. (2013), how can we envision learning skills with technology as opposed to learning from technology? The proposed XR technology prototype design takes steps toward learning with a technology philosophy to demonstrate how features can be used to prompt thinking and reinforce hierarchical development of deeper levels of PSL while learners are fully focused on the PSL tasks. See Table 1 for the proposed design of XR technology for psychomotor skill learning.

Table 1

Proposed Design of XR Technology for Psychomotor Skill Learning

Levels of mental processing	Learner	Generative activities for PSL / Dave's domain of psychomotor skill	Mental prompt: self-explanation, self-monitoring, self-testing, imagining, enacting
Selecting	generate meaning of new information by accessing and applying existing knowledge.	repetition, rehearsal, and review/ Imitation	Visual display of process or sequential steps/pattern with respect to psychomotor skill learning.
Organizing	organizes the information into a relevant structure by visually developing an association between actual movements and desired body movement.	modifying and creating new schemes/Articulation	Mental prompt guides learners to organize, monitor, and evaluate their own mental processes while learning.
Integrating	connects information with prior knowledge.	outlining and categorizing /Manipulation or Precision	Mental prompting stimulates ongoing appraisal, incorporation, and modification of body movements.
Elaboration	thinks of precise or accurate body movement and makes inferences about the information from existing knowledge.	mental images and creating physical diagrams / Precision or Naturalization	Mental prompting learner's attention to specific aspect of PSL process while learning in action.

Conclusion

This concept paper has explored a significant research gap in the domain of Psychomotor skill learning (PSL): the omission of mental processing and the lack of structured hierarchical skill development. Through a comprehensive examination of this performance gap, the multifaceted challenges that are associated with PSL are presented for learners, educators, instructional designers, and practitioners across various fields. Learners can attain a deeper level of engagement in psychomotor tasks through the integration of mental and motor processing. During PSL, the learners are deeply immersed in the psychomotor task purposefully interacting with the content (Jonassen et al., 1994) that leads to construction and generation of meaning being prompted by features of XR technology. This prototype challenges the conventional understanding of immersion, suggesting that the learners are neither immersed in the virtual world nor immersive environment; rather, they are reversely immersed in the psychomotor task through both mental and physical involvement. Finally, this prototype design suggests a transformative shift in how we perceive psychomotor skill learning. It emphasizes that true immersion in the content (i.e., psychomotor task) arises from actively, both mentally and physically, engaging in the task facilitated by the XR technology.

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