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Exploring Meta-Learning: Unveiling Progress and Obstacles - A Comprehensive Examination

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ABSTRACT

Educational international organizations have forecasted a radical transformation in how students learn, the content they learn, and the requisite skills in the near future. The advent of smart technologies is poised to revolutionize learning conditions, ushering in opportunities for transformative learning experiences and fostering more conscious, self-directed, and self-motivated learning endeavors. Meta-learning encompasses a suite of cognitive meta-processes through which learners consciously construct and manage personal learning models. It involves a progression of meta-skills that evolve hierarchically, facilitating the attainment of advanced levels of comprehension termed meta-comprehension. This article delves into the concept of meta-learning and delineates the meta-levels of learning through the lens of metacognition. Additionally, it explores the potential of smart technologies to serve as fertile ground for implementing meta-learning training strategies. The findings of this study contribute to a novel theoretical framework for meta-learning, bolstered by smart devices capable of supporting future meta-learners, or more aptly, meta-thinkers, in transcending conventional realms of knowledge and ascending to higher meta-levels of human intelligence.

Introduction:

Aristotle famously asserted that the inclination to learn is inherent in human nature. Yet, students frequently express dissatisfaction with the conventional methods of learning, finding them insufficiently motivating to take ownership of their education [1]. Concurrently, international educational bodies caution that learners, to a significant extent, lack the meta-skills requisite for navigating the challenges of the future, thus impeding their ability to become agents of change in society [2].

Contemporary societies stand on the cusp of monumental shifts that will inevitably reshape the landscape of learning [3,4]. The content, methods, and skills necessary for success are poised for radical transformation and extensive debate [5]. Artificial intelligence (AI) holds profound implications for educational institutions, aiming to foster innovative learning experiences and equip lifelong learners with the competencies essential for navigating both work and societal realms [3,4]. Smart technologies encompass artifacts imbued with properties of ubiquitous computing, including AI, the Internet of Things, and wearable technologies such as glasses, backpacks, or even clothing. These technologies afford learners unrestricted access to knowledge, transcending temporal and spatial constraints. Recent research underscores the potential of smart technologies in designing innovative learning environments conducive to self-directed and self-regulated learning [6,7].

The future of education promises learners boundless access to information. While this presents unique opportunities for personalized, self-paced learning tailored to individual needs and aspirations, it also poses challenges in navigating a data-saturated world, necessitating learners to develop critical skills for managing vast amounts of information effectively [8].

In this milieu, pedagogy and learning theories assume a pivotal role in supporting future learning endeavors, particularly within smart learning environments. However, relatively less attention has been devoted to the development of pedagogies and theories that meet the demands of future learning within smart environments [8].

The concept of metacognition, first introduced by Flavell, pertains to learners' awareness of their cognitive processes and their ability to regulate these processes [9]. Metacognition involves reflective skills and self-regulation of mental processes [10]. Nelson and Narens' metacognitive theoretical framework introduced the notion of meta-levels, delineating the interaction between object-level and meta-level processes in self-monitoring and self-regulation [11]. Subsequent studies have further elucidated the layered nature of metacognition [12]. In recent years, the emphasis on metacognition has intensified due to the imperative of preparing learners capable of leveraging digital technologies for self-directed learning [13]. Consequently, there has been a surge of interest in creating learning environments conducive to autonomous, self-directed, and self-regulated learning.

Given the rapid technological and societal transformations that will shape the future of learning, imbuing learning with a metacognitive dimension becomes imperative. Thus, we aim to present a nine-layered pyramid model of meta-learning grounded in metacognition and smart technologies. This hierarchical model posits that learning unfolds progressively as individuals ascend to higher meta-levels of self-learning. Rooted in the principles of metacognition, the meta-learning model incorporates elements such as emotional intelligence, spiritual intelligence, mindfulness, higher cognitive abilities, meta-motivations, and consciousness. By marrying metacognition with smart technologies, the nine-layered pyramid model of meta-learning seeks to enrich discussions on the role of learning theories in the digital era and underscore the pivotal role of metacognition in fostering learners' agency in the digital learning landscape.

The proposed nine-layered meta-learning model possesses several distinctive characteristics. It serves as a metacognitive learning taxonomy, with each meta-level of learning contingent upon metacognitive processes and skills that evolve progressively. Furthermore, the model acknowledges parameters such as emotional intelligence, spirituality, mindfulness, consciousness, and sub-consciousness (i.e., conscious and unconscious processing) that influence learning outcomes. Importantly, it is designed not only for conventional learning environments but also to seamlessly integrate with smart devices, facilitating the evolution of future smart meta-learning environments.

Materials and Methods

This article aims to ignite a discourse on the theory of learning in the digital age by introducing the concept of meta-learning. Specifically, we present a nine-layered pyramid model of meta-learning grounded in the principles of metacognition and smart technologies. Additionally, we provide a concise review of pertinent research concerning the role of smart technologies in cultivating meta-learning skills.

The first section delves into the theoretical underpinnings that laid the foundation for the conception of the meta-learning framework. We initiated our inquiry by exploring established learning theories, models, and taxonomies to elucidate prevailing approaches regarding the nature of learning, the learner's role, and the involvement of metacognition in learning processes. Furthermore, we synthesized recent neuroscientific research elucidating the neurophysiological processes underlying human learning.

In the subsequent section, we delineate the constituent elements of the nine-layered meta-learning model, with a particular emphasis on the centrality of metacognition. Within this section, we outline the meta-levels of learning, drawing insights from evidence-based research on the meta-cognitive procedures and skills requisite at each level, while also considering the influence of technology.

The final segment of this study is dedicated to exploring the potential of smart technologies in facilitating meta-learning training. We investigate the efficacy of various smart technologies, including artificial intelligence, with a specific focus on intelligent agents and learning assistants, smart wearable technology, mobile learning technologies, virtual immersive technologies, and robotics.

Theoretical Background

Learning Theories and Taxonomies:

Definitions of learning vary widely across disciplines, partly due to the diverse methodologies employed to measure its occurrence. Behaviorism posits learning as the acquisition of new behaviors, while cognitive learning theory defines it as a set of internal mental processes involved in information reception, decoding, storage, and retrieval. Constructivism views learning as a quest for meaning and understanding [14].

Blooms' taxonomy combines three hierarchical models to classify learning objectives based on their complexity and specificity, recognizing three interrelated domains: cognitive, affective, and psychomotor. Anderson and Krathwohl proposed a revised two-dimensional model based on Bloom's taxonomy, emphasizing the importance of metacognition. Marzano et al. described a two-dimensional hierarchical learning taxonomy that correlated six levels of information processing with three knowledge domains. Biggs et al. developed a layered taxonomy based on the complexity of learning outcomes, known as the SOLO taxonomy. Gagne introduced a hierarchical learning taxonomy based on the complexity of mental processes involved, structured into eight layers. While these theories exhibit similarities, they also harbor discrepancies in their conceptualizations of learning and the role of metacognition.

How the Brain Learns: The Neuroscientific Approach

Recent neuroscientific research underscores the dynamic nature of learning as a process of brain development and remodeling, facilitated by neurogenesis and neuroplasticity. Active and self-directed learning has been found to be more efficient, with rhythmic brain activity offering insights into self-directed learning. Brainwaves play a crucial role in explicit and implicit learning, with certain oscillations predicting specific learning outcomes. Human physiological processes, including hormonal regulation, influence cognitive and metacognitive functions, thereby impacting learning and memory capacity. Moreover, international organizations working on education policies foresee radical changes in the learning landscape, with a growing emphasis on metacognitive skills and continuous learning across various stages of life. In the context of constant change and technological advancement, discussions surrounding the future of learning in the digital era, the evolving role of learners, and the necessity for innovative learning frameworks and pedagogies have gained momentum.

A 9-Layered Meta-Learning Pyramid Model Based on Metacognition

The Building Elements of the Meta-Learning Model

Metacognition encompasses a set of regulatory meta-abilities and meta-skills that learners consciously employ to regulate cognitive and psychophysiological processes, thereby optimizing learning outcomes. It entails the meta-ability to monitor, regulate, and adapt internal cognitive processes, discern functional from dysfunctional mental states, and consciously select states conducive to unlocking their full learning potential. Metacognition reflects learners' awareness of their abilities, skills, and strategies, along with the flexibility to strategically deploy mental faculties to achieve higher objectives. It endows learners with the capacity to oversee learning, interrogate the reasons behind knowledge, contemplate its significance, and pursue self-understanding [12,41].

Metacognition is structured upon eight distinct yet interrelated pillars (Figure 1) [12,41,42]:

1. Metacognitive Knowledge: This pillar pertains to learners' ability to construct knowledge, particularly concerning their cognitive functions, by creating meta-representations of this knowledge. It necessitates an understanding of cognition, its operations, and its hierarchical organization. Furthermore, it requires a profound comprehension of the process of acquiring meta-abilities and meta-skills that enable "learning to learn" operations.

2. Applied Metaknowledge: After gaining experience, reflection, and systematic practice, learners should apply their metacognitive knowledge and strategically utilize their mental tools based on the parameters defined by a task, problem, or situation. Applied metaknowledge entails consciousness of personal strengths and weaknesses and the ability to transfer existing knowledge to novel contexts.

3. Self-Observation: This pillar involves real-time monitoring of both external (exteroception) and internal (introspection) processes during learning. It represents internal attention and control, illuminating the sources of knowledge. Self-observation evolves progressively with systematic training.

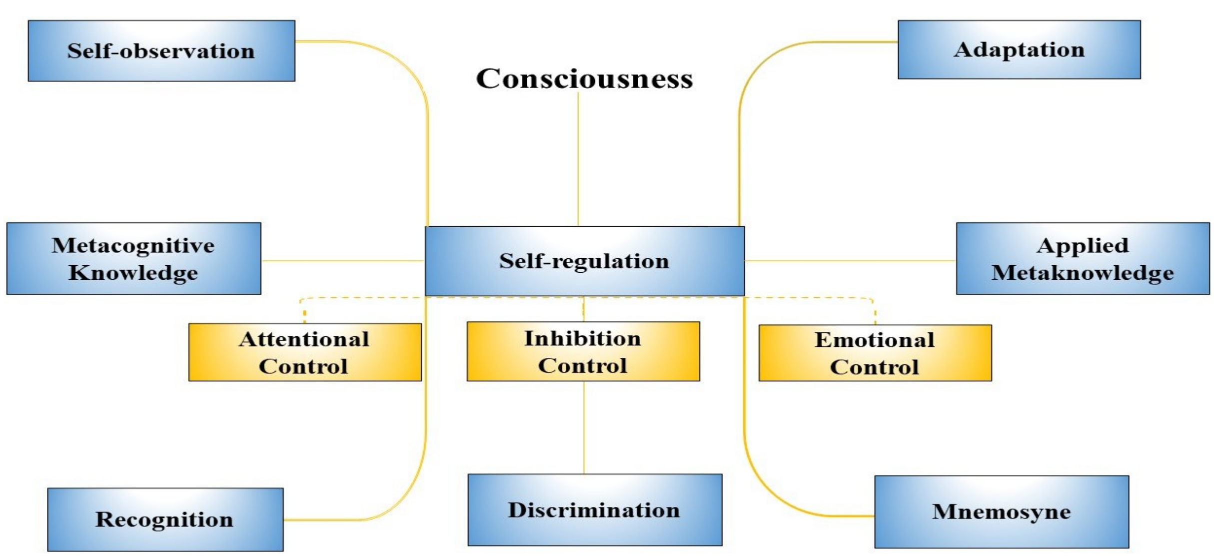
4. Self-Regulation: Learners' capacity to manage cognition and rectify any observed disturbances interrupting the proper functioning of cognitive and psychophysiological processes that impact learning.

5. Adaptability: Individuals' ability to adjust their mental and emotional functioning, as well as their learning behavior, in alignment with personal goals and learning demands.

6. Recognition: This pillar denotes learners' ability to recognize and be cognizant of their mental and emotional states and comprehend their influence on learning. It also encompasses the ability to recognize others' states of mind as a means of learning from them.

7. Discrimination: Filtering and selectively choosing essential information and knowledge in a learning scenario, distinguishing between the known and unknown elements in a problem, and identifying helpful variables in learning.

8. Mnemosyne: This pillar signifies a state of awakened consciousness, characterized by the voluntary maintenance of a state of relaxed awareness and readiness to achieve peak performance. It symbolizes internalized knowledge that motivates and propels learners toward independence, mindfulness, and academic achievement.



Higher Mental/Emotional Abilities are considered integral components of the proposed framework, as learning is now perceived as a dynamic process aimed at nurturing learners' talents, fostering excellence, and preparing them as innovative leaders [43]. These abilities engage cognitive functions such as attention, working memory, mental imagery, and executive functions [44]. They are also linked with complex thinking processes like problem-solving, analytical, and critical thinking [45]. Many researchers associate higher cognitive abilities with executive functions, encompassing various control and self-regulation skills such as inhibition and attentional regulation [46]. In the emotional domain, higher emotional ability entails not only perceiving but importantly regulating emotions [47].

Emotional Intelligence plays a pivotal role in the meta-learning model, as emotions indicate readiness to learn. Self-management of emotions significantly influences learning outcomes [41,48]. For example, positivity can enhance creativity and innovation in learning, whereas negative emotions may predict academic underachievement [49]. Spiritual Intelligence is another essential element of the meta-learning pyramid. It assists learners in avoiding attachment to phenomena and drives them to seek meaning, reasons, and genuine knowledge. Given today's limitless access to knowledge, spiritual intelligence can aid learners in making moral decisions regarding knowledge use, coping with challenges, and fostering learning through the cultivation of humility, kindness, and generosity. These traits and skills are vital for the development of healthy citizens and societies [50–53].

Consciousness: Future education is tasked with preparing students for a conscious society where individuals can learn, think, and respond rapidly, accurately, and wisely [12,54,55]. Learning is also contingent upon states of consciousness [12,41,56].

Sub-conscious Learning: Traditionally, learning has focused on training the conscious mind. However, recent studies challenge this causal stance of conscious will, demonstrating that decisions and actions are initiated even when individuals are unconscious of the goals or their motivating effects on behavior [57,58]. Stimuli presented below awareness thresholds can influence motivational states, thereby significantly impacting learning behaviors [59]. Subliminal training interventions, employing techniques like masked stimuli and subliminal priming, have shown improvements in cognitive operations, self-regulation skills, and academic achievement [60–62]. Moreover, research suggests that individuals in states of reduced awareness are more receptive to learning and accepting new knowledge [63]. Sub-conscious mechanisms are responsible for processes such as creativity, unlearning, or relearning new skills and habits. Modern research recognizes the significance of the subconscious in the meta-learning framework supported by smart technologies [67–72].

Mindfulness: Being mindful empowers learners to exert greater control over learning processes, cope with stress, and avoid forming limiting mindsets. Mindfulness, as a form of metacognition, cultivates self-awareness, emotional regulation, and attentional control. Contemplative practices in education nurture positive learning habits, enhance self-regulation skills, heighten perceptual awareness, and reduce self-bias. These practices also support the neural networks of self-awareness [42,49,73–77].

The 9-Layered Model of Meta-Learning: Senses and Interest Stimulation

Interest and curiosity serve as inherent driving forces stimulating and nurturing the desire for knowledge and learning. Interest directs attention towards stimuli, motivates goal setting, and determines learners' readiness to embark on the meta-levels of learning [78]. In a state of interest, cognitive and affective qualities intertwine to make learning less effortful, self-regulated, and enjoyable, while also fostering a predisposition for re-engagement. Higher cognitive abilities such as attention and memory operate more efficiently when learners' interest is piqued, ensuring better processing of sensory stimuli [12,80]. As we navigate the fourth industrial revolution, characterized by continuous learning and upskilling, future education should prioritize cultivating enduring interest in cutting-edge knowledge and technologies, particularly among social groups such as women, people with disabilities, and minorities. Interest development is gradual, with learners initially depending on external support until they become conscious of their genuine interests. Hence, meta-learning environments should be designed to stimulate learners' attention by offering activities characterized by novelty, surprise, and ambiguity. Integrating academic subjects with existing interests, eliciting positive emotions, and addressing immediate needs can further facilitate this goal. Problem-based learning, group work, and personalized content and context can also enhance interest [78,79].

Data Research and Collection

Searching is viewed as the gateway to self-directed learning [82]. The subsequent step in the learning-to-learn hierarchy involves transforming interest and curiosity into data-seeking behaviors. Data can be understood as discrete and objective observations, facts, or symbols lacking meaning until they are processed and structured [83]. Research indicates that students often lack skills in data research, encountering challenges in designing research, collecting, and analyzing data, which can lead to academic underachievement [84]. In the era of big data, learners must navigate vast amounts of digital and non-digital data to lay the groundwork for learning, problem-solving, and decision-making [85]. Data-driven learning is commonly employed in foreign language learning to facilitate guided discovery tasks, where students act as researchers learning from authentic data. This approach promotes self-regulated learning, enhances awareness skills, and fosters learners' agency, autonomy, and motivation [86]. Learning environments should offer opportunities for data searching supported by digital technologies. Meta-learners should conduct surveys and online searches in databases, utilizing statistical methods and tools [85,87].

Information Organization and Interconnection

The challenge at the next meta-level of the learning hierarchy involves transforming data into meaningful and purposeful information. Information refers to processed data that have been understood and given purpose [83]. Learning at this meta-level requires learners to apply meta-strategic manipulations to extract meanings from datasets, organize information, and construct information clouds [12]. In cognitive psychology, the theory of information processing underscores the importance of mechanisms by which an individual's brain records, stores, and retrieves information [88]. Meta-learners need to develop various information processing meta-skills, including association and organization skills, to understand relations between elements and construct taxonomies [83,89]. Additionally, information manipulation requires meta-learners to possess memory control meta-skills and meta-strategies [88,90]. Learning should occur within information-rich environments engaging hybrid methodologies by blending digital technologies with meta-learning strategies [90,91].

Knowledge Structuring and Creation

Experience, coupled with reflection and deeper information processing, initiates mental procedures contributing to knowledge creation [92]. Transitioning from information to knowledge, learners begin to discern patterns and rules between data and information, thus structuring the initial framework of knowledge [12]. Learners with well-structured knowledge can comprehend their surroundings, establish connections between new and existing knowledge, predict outcomes, and deliberate judgments during the learning process [93]. Therefore, the meta-level of knowledge creation involves higher mental skills such as analysis, reflection, and synthesis of multiple sources of information [83]. Memory plays a pivotal role once again in conceptualizing knowledge, aiding in understanding concepts, principles, theories, models, and classifications [94]. In the 21st century, knowledge creation is viewed more as a communal endeavor rather than a personal challenge. Learners should be capable of generating collective knowledge by collaborating on authentic problems, exchanging real ideas in open workspaces. Knowledge-building environments, supported by digital technologies, could significantly transform schools into knowledge-creating organizations [95].

Specialization Development and Filtering Sets of Knowledge

Expertise entails superior performance in a specific domain of knowledge, fostering even more independent, autonomous, and self-regulated learning. In scientific research, for example, expertise involves identifying the boundaries of knowledge by discerning how theories contradict each other and why certain laws may not always apply to complex problems or phenomena. Expertise also encompasses exceptional cognitive skills, which, although automated to some extent, remain under human control and result from systematic practice. Mnemonic skills, derived from well-trained memory control abilities, represent a form of expertise, as does speed learning, including rapid reading, listening, or calculation skills [12,41,54,90,96]. Experts demonstrate superior performance compared to novices because they are more adept at navigating smaller problem spaces and identifying when knowledge is applicable or inapplicable under problem constraints [96]. Filtering skills refer to the meta-ability to be selective and determine the factors essential for achievement. Meta-learners distinguish between cognitive and emotional situations, selecting the most beneficial, positive, and supportive approaches for success, fulfillment, and personal development [41,97]. Faculty mentors, disciplinary networks, and knowledge-restructuring techniques can significantly support specialization development [97].

Self-Actualized Learning

Optimal learning requires that meta-learners, in addition to fulfilling basic physiological needs, strive to satisfy a higher growth need known as self-actualization. Self-actualization refers to learners' internal drive to expand their understanding and achieve their full potential in learning [98]. In the meta-learning pyramid, self-actualization represents meta-abilities that maximize learning potential, signifying the transition from interest and curiosity to a passion for learning and knowing [12,50,98,99]. Self-actualized meta-learners value the benefits of learning, seek deeper meaning in learning, and contemplate the ethical issues surrounding the use of acquired knowledge. Meta-learning involves a more accurate perception of reality as meta-learners discard imposed knowledge and mental obstacles, such as procrastination or overlearned dysfunctional beliefs, using critical tools to achieve reasoning autonomy [12,50]. Self-actualization fosters empathetic learning, where learners embrace knowledge diversity across societies and cultures, using knowledge to make sustainable decisions that promote well-being [100]. Among the most critical objectives in meta-learning environments, whether traditional or digital, is the creation of learning experiences that promote self-actualization. Meta-learners should seek learning experiences that offer opportunities to perceive knowledge from different perspectives using reflective technologies such as virtual reality and artificial intelligence. Smart technologies integrating data from various life circumstances can support learners in developing better awareness of how they can reach their full potential in learning [67,99].

Learning to Learn from the Unknown, Acceptance of Universal Laws

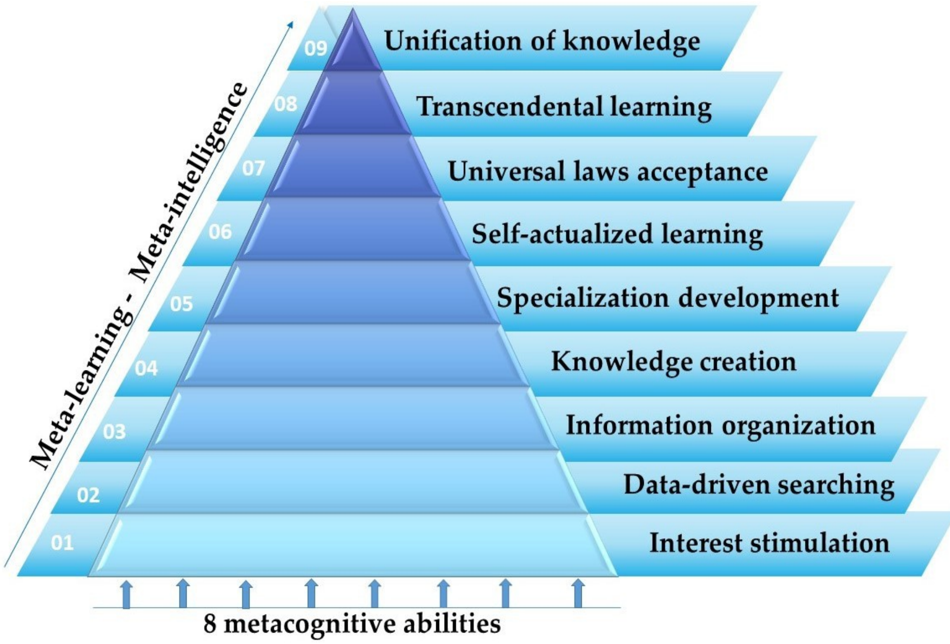
As learners, we often assume that we possess all potential knowledge and tend to deny alternative knowledge contradicting established beliefs. However, significant scientific developments typically arise from conflicts between new and existing theoretical insights that challenge common sense. For example, Max Planck's exploration of the statistical properties of radiation led to the development of quantum mechanics, while Einstein's inquiries into observers traveling at the speed of light contributed to the theory of relativity [101].

Transcendence Learning

Learners transition to meta-learners, or more precisely meta-thinkers, when they can transcend the current state of knowledge and progress to a higher level of comprehension [12,41]. The critical aspect for learners is not following a predetermined path but discovering or developing a passion for learning that motivates them to carve out their own path, even in uncertain terrain. This encourages meta-learners to surpass limitations and stereotypes, utilize all available mental capacity, and find their way to holistic learning [102]. This occurs when learners find a transcendent purpose, hitching their wagon to something larger than themselves. Only then can they unlock their true potential and realize the role they will play in shaping future societies. At this meta-level, self-oriented motives for learning, such as seeking an interesting or enjoyable career, are insufficient. Instead, learning demands dedication and a desire to pursue a higher purpose. This is why transcendental learners, such as scientists, can work on seemingly mundane tasks with undiminished interest and dedication [103].

Unification of Knowledge

Scientists often refer to the "theory of everything" to describe the ultimate theory of the cosmos. This theory represents a hypothetical, unitary, all-encompassing framework that fully explains and connects all parts of the world [101,104]. It serves as the modern counterpart to the ancient Greeks' reductionist ideal, embodying a viewpoint that has improved humanity's condition and remains central to modern science [104].



Smart Meta-Learning Technologies

Artificial Intelligence (AI): AI plays an increasingly vital role in meta-learning processes. Customizing and personalizing learning content according to learners' needs reinforce motivations, enhance curiosity, and help meta-learners achieve higher goals. Crucially, AI provides feedback, essential for reflection processes [54,105,106]. AI focuses on experiential learning, the cornerstone of knowledge creation. It enriches experiences and aids in information uptake and retention, enabling memory control abilities to thrive. Additionally, AI facilitates access to global knowledge and supports learners by identifying their strengths and weaknesses during learning. AI learning environments align with metacognitive principles, empowering learners to address personal weaknesses as learning opportunities and master existing skills [105–107]. Importantly, AI breaks down barriers faced by people with learning difficulties, physical impairments, or discrimination, ensuring equal access to learning opportunities. Thus, the concept of meta-learning, with AI's contribution, embraces all social groups, aiming to prepare meta-learners equipped with leadership skills and collective consciousness [109].

Intelligent Agents: Teachable agents, based on the "learning by teaching" metacognitive strategy, enable learners to take on the role of teachers, intending to teach their virtual agents new concepts [110]. Research indicates that teachable agents, combined with recursive feedback, enhance students' meta-learning abilities and critical thinking skills. Students improve their understanding of knowledge by observing, understanding, and modifying their agent's performance [111,112]. Teachable agents also assist students in developing hierarchical reasoning skills [110].

Chatbots/AI Learning Assistants: Chatbots serve as conversational or interactive agents that take on roles such as teacher, mentor, or assistant, responding to users in real-time [113]. Working with conversational agents gradually teaches learners to explain themselves, enhancing knowledge acquisition and retention. As virtual teaching assistants, chatbots encourage self-reflection through conversations and interactions, providing smart feedback based on learners' strengths and weaknesses. They also recognize users' psychological needs and provide constant support to lower stress, encouraging learners to view failures as learning opportunities [114–116].

Smart Wearable Technologies: Wearable devices, such as smartwatches and smart headbands, offer various characteristics like biofeedback and sensory physiological functions [117]. Smart wearables support learning by providing feedback and support regarding learners' mental readiness and optimal learning states. They assist users in making optimal judgments, adopting self-regulating behaviors, and establishing positive habits and functional thinking patterns [120,121]. Smart headbands measure brainwaves, aiding learners in being aware of their mental and emotional states and levels of attention and anxiety. Combined with technologies like virtual reality, they provide opportunities to train attention and utilize it as a meta-learning tool [122–125].

Smart Mobile Learning Technologies: Mobile learning (M-learning) technologies leverage wireless internet and mobile devices to support learning, including mobile phones, smartphones, and tablet PCs [126]. They provide features like ubiquity, flexibility, and portability, encouraging learners to become knowledge creators. M-learning enables learning anytime and anywhere, offering unlimited access to learning resources and fostering openness to creative ideas and active construction of new concepts within different learning spaces [127].

Virtual Immersive Technologies: Virtual reality (VR), augmented reality (AR), and extended reality (XR) are immersive technologies that blend machine learning and AI techniques to enhance user experiences [3]. VR and AR, in particular, facilitate behavioral and emotional change by generating transformative experiences and altering individuals' worldviews. They improve higher mental abilities such as executive functions, mental imagery, and problem-solving through psychological techniques implemented within immersive virtual environments [36–41,67–72]. VR hypnosis techniques induce semi-consciousness to help learners deal with established beliefs and dysfunctional memories, maximizing learning outcomes and reducing resistance derived from conscious control processes [68,69]. VR trains various meta-abilities and meta-skills, such as self-observation, self-regulation, and adaptability, making it a potent tool for meta-learning [67–72,90].

Robotics and 3D Printing: Robotics and 3D printing promote self-learning skills by encouraging learners to apply theoretical knowledge to real situations, fostering a deeper understanding of complex concepts. Learners develop skills such as creative thinking, ingenuity, and innovative thinking, alongside self-consciousness and collective consciousness. They are motivated to learn with the intention of advancing science and finding solutions for sustainability and global well-being [131].

Discussion

In this study, we introduced the concept of meta-learning to describe the progressive process of transitioning through nine meta-levels of conscious and self-directed learning. Our nine-layer pyramid model of meta-learning, built on the principles of metacognition with the integration of smart technologies, delineated the metacognitive procedures, meta-skills, and meta-abilities necessary for advancing learners' states of knowledge, learning, and intelligence.

Our proposed model shares similarities with established theoretical models, such as Bloom's taxonomy, in its focus on discrete levels through which learning progresses. However, our model places special emphasis on the role of attention and memory in regulating learning procedures. It is fully grounded in metacognition, distinguishing it from previous theories that acknowledged a limited role for metacognitive processes. While some previous theories primarily aimed to assist teachers in developing instructional strategies, our model is designed to primarily support self-directed learning, while still being applicable to teachers. Additionally, our model is adapted to the skills required in the 21st century and the role of learning technologies in future education.

Future learning environments, particularly digital ones, are expected to play a crucial role in education. Our model aimed to provide a theoretical framework to encourage students to manifest and develop their inherent willingness to learn by better understanding and managing the mechanisms that promote learning.

Smart technologies and AI were identified as promising tools for equipping lifelong learners with the metacognitive skills needed for success in future society. These technologies train learners to be more aware of how learning occurs, control their mental and emotional states, recognize strengths and weaknesses, and master skills such as problem-solving and critical thinking. Importantly, smart technologies aim to support learners' internal motivations, which are essential for meaningful and metacognitive learning.

It is essential to note that while smart technologies facilitate learning, they are not meant to replace learners' goal setting, planning, and self-management. Instead, the goal of meta-learning is to use smart learning technologies to support the development of metacognitive skills. Smart meta-learning environments should provide training to help learners develop a wide range of meta-skills needed for critical thinking, innovation, responsible citizenship, and future readiness.

Although our nine-layered meta-learning model focuses on the processes of achieving wiser learning, it has the potential to support both students and teachers in educational programs. However, to fully utilize smart technologies for meta-learning, learners and educators must develop awareness of their potential and capabilities.

Our proposed framework, based on metacognition and smart technologies, can be viewed as a model for self-directed and lifelong learning. It covers various meta-skills needed across different domains, including physical, intellectual, socio-emotional, and spiritual aspects. Our aim was to contribute to the discourse on the future of learning by proposing a theoretical framework that places the learner at the center of learning procedures, based primarily on metacognitive principles.

Moving forward, our future research will focus on assessing the feasibility of the proposed framework through experimental studies. Additionally, the framework can guide the design of smart meta-learning environments and inform the implementation of teaching strategies. Future research could explore the effectiveness of the nine-layered pyramid model within different educational contexts and with learners of diverse characteristics, utilizing smart technologies.

Conclusions

This study introduced a nine-layered meta-learning pyramid model based on metacognition and smart technologies, aimed at guiding future learners towards transcending conventional states of knowledge and progressing towards higher levels of human intelligence, termed meta-intelligence. Central to this process is the development of higher motives, termed meta-motivations, as described in self-determination theory by Deci and Ryan, which involves the internalization of motivations.

The proposed model synthesized knowledge from established theories of learning, metacognition, spiritual and emotional intelligence, mindfulness, and other learning theories. It underscores the pressing need to equip future learners with meta-skills essential for driving change in schools and society. Additionally, the model integrates smart technologies as a crucial component of meta-learning. Indeed, evidence-based research suggests that smart technologies have the potential to support meta-learning processes by offering smart feedback that fosters reflection and adaptation, as well as by providing transformative experiences that induce states of consciousness conducive to deep and meaningful learning. Our study suggests that optimal meta-learning training involves a thoughtful blend of meta-learning strategies supported by smart technologies.

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