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REFLECTION ON THE FIELD

Evolutionary Perspective on Human Cognitive Architecture in Cognitive Load Theory: a Dynamic, Emerging Principle Approach

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Abstract

Adopting an evolutionary approach to substantiate major characteristics of human cognitive architecture has been one of the major recent developments in cognitive load theory. According to this approach, human cognitive architecture is a natural information processing system which can be described by five general principles. This paper attempts to (1) identify the scope of applicability of these principles in natural information processing systems of different levels of complexity, (2) reconcile the coexistence of implicit (primary) and controlled (secondary) processes within the same human cognitive architecture, and (3) incorporate motivational factors into the evolutionary approach to human cognitive architecture. The paper suggests two principal modifications to the traditional formulation of the evolutionary approach. Firstly, natural information processing systems are viewed as dynamically evolving systems with new principles added with increasing levels of complexity of the systems. Secondly, a new (the explicit intention to learn) principle is added at the level of human cognition. This sixth principle is expected to address (1) the emergence of controlled mechanisms dealing with biologically secondary information as expressed by conscious processing in working memory and (2) the role of learner motivation in such processes from an evolutionary perspective. The paper concludes with discussion of theoretical and practical instructional implications of the proposed modifications.

Keywords Natural information processing systems · Human cognitive architecture · Evolutionary approach · Controlled information processing · Learner motivation

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One of the major developments in cognitive load theory over the last 20 years was adopting an evolutionary approach to substantiate major characteristics of human cognitive architecture relevant to this theory. According to this approach, human cognitive system belongs to natural information processing systems that have similar general structural characteristics and operational principles (Sweller, 2003; Sweller & Sweller, 2006; see Sweller, Ayres, & Kalyuga, 2011, for a comprehensive overview, and Sweller 2022, for a most recent description). In particular, a close analogy was established between the human cognitive system when dealing with the acquisition of the domain-specific knowledge for which education and training institutions were developed and biological evolution by natural selection. Five principles were suggested to explain the operation of these two natural information processing systems (the first two principles relate to the acquisition of information, the following two principles to the processing and storing of information, and the last one to the use of that stored information):

1) *The randomness as genesis principle*, which shows how any principally new for a system information, i.e., information that is not available directly from other sources, originates from random, generate-and-test, search processes (random mutations in biological evolution system or problem-solving using general heuristics such as means-ends analysis or trial-and-error technique in human cognition).
2) *The borrowing and reorganizing principle*, which describes that most of the information is directly borrowed by the system from other sources and then actively reorganized rather than copied exactly (e.g., most of the content of individual human knowledge base originates from other sources, although it is reconstructed, reorganized, and integrated with already available knowledge so does genetic information in a biological organism's genome).
3) *The narrow limits of change principle*, which describes that when presented with a novel environment, the system has a mechanism that allows only very small, incremental changes to the available information to prevent damaging its functionality (a small number of random mutations at a time in the biological system limited by the epigenetic system which determines the location and number of mutations in response to the external environment; limited processing capacity and duration of working memory in human cognition).
4) *Information store principle*, which states that any natural information processing system includes a store of information that accumulates all the acquired (through random search or borrowing) information and guides the operation of the system and its interaction with the environment (genome for the biological evolution system and long-term memory for human cognition).
5) *The environmental organizing and linking principle*, according to which there is no narrow limits of change when the system operates in a familiar environment, i.e., when the relevant information is already available in the information store (in the biological evolution, the epigenetic system turns relevant genes on or off depending on environmental signals, affecting changes in the behavior of a genome and resulting in different phenotypes; in human cognition, the activated prior knowledge in long-term memory removes working memory limitations by

encapsulating many elements of information into larger chunks). The environment plays similar roles in both systems with working memory analogous to the epigenetic system and long-term memory analogous to the genetic system.

Another essential addition to evolutionary perspective on human cognitive architecture in cognitive load theory was accepting the evolutionary educational psychology's distinction between two major types of human knowledge and abilities based on their evolutionary origins and significance (Geary, 2005; 2007; 2008). The first type—biologically primary knowledge and abilities—represents the intuitive type of knowledge that humans evolved to acquire rapidly and implicitly by being involved in the corresponding types of environments. For example, skills in listening to and speaking a native language are usually acquired implicitly within a social community or group, as are basic intuitions about physical environments. Biologically primary knowledge evolved to enable us to process and respond to specific forms of information in the environment that has been important for survival during biological evolution.

Biologically primary knowledge is learned early in life, implicitly and unintentionally, while a learner is involved in appropriate common everyday activities (such as communicating in small groups, playing, and exploring surrounding environment). This knowledge is mostly inaccessible to conscious control and does not require working memory resources. It is encoded directly into long-term memory without being consciously processed by working memory. The role of biologically primary knowledge in human cognition could also be viewed through the information store principle. Similar to other natural information processing systems that build extensive stores of information patterns to function effectively in their corresponding environments, the drive for extensive knowledge base is so critical to human cognition that we actually evolved to have "inborn" potential knowledge bases in many essential areas of our common everyday life activities—and this is the base of biologically primary knowledge that we are genetically predisposed to acquire rapidly in an implicit, automatic way.

However, biologically primary, implicit knowledge is not the type of knowledge we usually learn in organized educational institutions. Here, we acquire scientific knowledge, writing and reading skills, which are examples of what is considered biologically secondary knowledge in evolutionary educational psychology. Biologically secondary knowledge is slow to acquire and heavily dependent on working memory. We have not evolved to implicitly acquire this knowledge and are not naturally motivated to do it. It is culture-specific knowledge that requires conscious, explicit, and effortful processes in working memory. Although secondary knowledge and abilities originated from biologically primary knowledge, conscious reflection on this knowledge through cognitive processing in working memory was essential in this transition (Geary, 2005).

Lespiau & Tricot, (2022a; 2022b) suggested that the division between biologically primary and secondary processes in evolutionary educational psychology could be compared to dual-process theories of reasoning, where a corresponding type of thinking, which is fast and independent of conscious processing in working memory, is called intuitive thinking (type 1). In contrast, the other, slower type of thinking that requires conscious thought is called analytical thinking (type 2) (e.g., Barrouillet, 2011; Evans, 2008, 2011; Evans & Stanovich, 2013). Accordingly, primary knowledge mechanisms could be compared to type 1 mechanisms in dual-process approaches, as they are also unconscious, implicit, linked to evolutionary rationality and not dependent on cognitive abilities (even though type 1 and primary knowledge could not be equated—for example, reading skills represent type 1 mechanisms for many adults, even though they belong to secondary knowledge). Similar to biologically secondary processes, type 2 mechanisms are also conscious, explicit, linked to individual rationality and dependent on working memory processes (Lespiau & Tricot, 2022a).

The cognitive processes involved in learning primary and secondary knowledge are significantly different. An essential condition for learning secondary knowledge is conscious effortful processing in working memory—the very component of our cognitive architecture that evolved to effectively cope with novelty and changes in the environment. While biologically primary knowledge relies on evolved brain systems that automatically focus our attention on relevant features and respond to information patterns that are essential for our biological survival, during learning, secondary knowledge is heavily dependent on the explicit, conscious cognitive mechanisms. Therefore, instructional design principles in general, and specific recommendation by cognitive load theory, are mostly related to learning of biologically secondary/explicit types of knowledge.

When considering the above formulation of the principles of natural information processing systems in general and applying them to human cognitive architecture, there seems to be apparent incompleteness in the current description of the evolutionary approach within a cognitive load theoretical framework. Firstly, the theory refers to the analogy between human cognitive architecture and biological evolution by natural selection as an information processing system (Sweller, 2022; Sweller & Sweller, 2006). These are two specific natural information processing systems. Do the same principles apply to all other natural information processing systems? If not all, then to what levels or types of such systems does the analogy apply? Apparently, higher-level biological organisms (e.g., mammals) are included. Would the principles apply to all evolved biological systems? What about other than biological systems? In short, the range of applicability of the proposed principles is not clearly specified. Of course, such a specification is not critical to the theory, as the purpose of establishing the analogy was to substantiate the main characteristics of human cognitive architecture. Still, the limits of applicability are important for general understanding of the big picture in the theory. Therefore, the first question that will be addressed in this paper to complete the evolutionary approach is the scope of natural information processing systems involved.

The different nature of processes involved in dealing with primary and secondary types of information in human cognition raises another issue that needs to be clarified to place these processes within a unified view of natural information processing systems. According to the narrow limits of change principle in the traditional evolutionary approach, working memory with its limited processing capacity when dealing with novel secondary information represents a mechanism for reducing the scope of possible changes to the information store (knowledge base). Still, another critical role of working memory in human cognition—inhibiting the execution of the primary knowledge-based activities and engaging controlled, conscious processes in working memory to successfully cope with novel environments—is seemingly ignored. This type of function is apparently absent in the biological evolution system considered analogical to human cognitive architecture, as well as in other biological organisms that rely only on implicit mechanisms and abilities (as equivalents of human biologically primary knowledge and abilities)[1]. Therefore, the traditional set of principles (excluding the narrow limits of change principle) applies well to describing the operation of such systems, as well as to processes involving biologically primary information and abilities in human cognition. The narrow limits of change principle in such processes do not apply and do not need to be applied (in other words, it is redundant or suppressed in this situation), as there is no conscious processing of secondary information in working memory (in case of human cognition), and primary information or its equivalents involved in such processing include already implicitly acquired patterns in the information store that are used to guide the operation of the system according to the environmental organizing and linking principle.

However, in human cognition, precisely the above-mentioned role of working memory as conscious, controlled information processor is responsible for the development of biologically secondary knowledge. Reconciling the concurrent presence of implicit (primary) and controlled (secondary) processes within a single architecture guided by the same set of principles common to all natural information processing systems (even though some could be suppressed in some situations, like in the above case) is the second question to be addressed. Stating that human cognitive architecture analogous to evolution by natural selection is associated only with the acquisition of secondary information (Sweller, 2022) does not quite answer this question without breaking the universality of the architecture for all natural information processing systems, as primary processes are also part of human cognition within the same architecture.

In this respect, Bjorklund's, (2022) notion of the "evolutionary mismatches"—conflicts between evolved psychological mechanisms of primary learning and their utility in modern environments that require mechanisms of secondary learning—might have captured some important aspects of this problem. The environments in which human primary learning skills evolved and current learning environments are vastly different, and this could make learning difficult and not enjoyable to learners, particularly when learning abstract literacy, numeracy, and scientific skills, which require extrinsic motivation and explicit instruction for their acquisition. The major issue is that such evolutionary mismatches should be dealt with within the same

[1] In the case of biological evolution, there is a seemingly similar mechanism partially responsible for the inhibition of the expression of genes in one type of tissue or another, which appear analogous to the inhibition of irrelevant information in working memory (e.g., even though the genome is encoded in the DNA in all cells and tissue types, but there are differences in the expression patterns of genes in one type of tissue or another, such as the brain or heart, or in different areas of the same organ). However, this mechanism could hardly be considered as associated with any form of controlled, intentional processes.

information processing system (cognitive architecture), although using different mechanisms.

Finally, closely related to the previous issue with placing both primary and secondary processes within the same human cognitive architecture is the role of motivation in human cognition from the evolutionary perspective. Explicit and effortful processes in working memory require intentional engagement and motivation for the acquisition of biologically secondary knowledge, which are mostly ignored in the current formulation of the evolutionary approach to human cognitive architecture in cognitive load theory. There have not been major breakthroughs in integrating motivation into information processing models in cognitive psychology in general and cognitive load theory in particular. Also, from an educational evolutionary psychology viewpoint, Geary & Xu, (2022) noted that academic motivation had not been sufficiently explored from an evolutionary perspective. Incorporating motivation into the evolutionary approach to human cognitive architecture in cognitive load theory is the third issue to be addressed.

To resolve these issues, the current paper proposes two principal modifications to the current way of formulating principles guiding the operation of natural information processing systems. Firstly, natural information processing systems are viewed as dynamically evolving systems with new principles added with increasing levels of complexity of the systems. Secondly, a new principle is added at the level of human cognition in addition to the previously formulated five principles. This additional principle expresses the emergence of controlled, secondary information processing mechanisms on this level as realized by conscious processing in working memory, as well as the role of learner motivation in such processes from an evolutionary perspective. The following two sections will describe the proposed two modifications accordingly, while the final section will discuss their theoretical and practical instructional implications.

Emerging Principle View of the Evolution of Natural Information Processing Systems (Downward Extrapolation)

To determine the range of applicability of the five principles of natural information processing systems below the currently considered levels of biological evolution by natural selection and human cognitive architecture (Sweller, 2003; 2022), it would be helpful to explore the possibility of extrapolating this evolutionary approach to lower-level natural information processing systems: could the information processing aspects of the operation of such systems be described by at least some, if not all, of these principles? If it is possible to extend the principles of natural information processing systems below the level of biological evolution by natural selection to all biological systems, and even down to non-organic systems, the extension could increase the range of applicability of these principles and also give us some insight into possible origins of human cognitive architecture as an evolved system.

If information is considered an attribute of objects of any nature that represents stable patterns in their organization (e.g., Stonier, 1997) and if information processing is defined as the process of transmitting and adopting such patterns, then any organized (non-chaotic) matter may carry information as its feature. To take an opposite extreme of human cognitive system, even atomic and sub-atomic particles maintain their organizational patterns and engage in some forms of information processing that could be described with at least some of the principles of operation of natural information processing systems. In the example of atoms, these objects preserve ("store") their specific stable patterns of atomic shells as exact electron energy levels (the information store principle).

These stable structural patterns may have emerged during the early stage of the evolution of the universe following rather random sub-atomic particle interactions (the randomness as genesis principle). For example, hydrogen and helium atoms emerged several hundred thousand years after the Big Bang from the chaotic, hot, dense plasma of protons, electrons, and photons. When the universe began to expand and cool down, electrons and protons started to interact and combine to form the first elements' atoms (Grochala, 2015). Similar processes resulting in formation of sub-atomic particles, such as protons, neutrons, and electrons, happened earlier, immediately after the Big Bang, when the universe was a hot, dense plasma of photons, leptons, and quarks (Ryden, 2003). Furthermore, these emerged information patterns "guide" interactions of particles and atoms with their external environments (the environmental organizing and linking principle). For example, the stable patterns of atomic shells with exact electron energy levels determine exactly how the atoms combine with other atoms to form more complex molecular structures.

With the emergence of more complex, organic systems, the narrow limits of change appeared to prevent this complexity from being damaged by some big random changes by allowing only gradual, incremental modifications. Such complex systems also developed mechanisms for borrowing their organizational patterns, eventually resulting in efficient self-reproduction in biological systems. Stable organizational patterns in the information store of such information processing systems (in the case of human cognition-organized knowledge structures, schemas, or conceptual knowledge) guide the interaction of the systems with their environments. Even though they are significantly shaped by such interactions, these structures may maintain their relative stability in the face of potential random modifications. The mechanism of experiential canalization (e.g., Blair & Raver, (2012); Gottlieb, 1991) that restricts the expression of underlying genetic and basic biological variation (so that successful traits are maintained in the presence of mutations and genetic variability resulting from sexual reproduction) could be relevant to such processes, potentially explaining the role of human's conceptual knowledge or cognitive schemas as representations of these constraints in the expression of information stored in long-term memory.

Thus, the three principles—information store, randomness as genesis, and environmental organizing and linking principles—could be potentially applied even to simple non-organic information processing systems. All five principles (together with some associated supporting mechanisms) apply to systems that are more advanced, such as complex organic and biological systems to ensure their flexibility and adaptivity to environmental changes (Kalyuga, 2011).

It appears possible that the essential characteristics of the human mind evolved from the fundamental information processing features of nature in general. This would make our impressive scientific abilities of building huge knowledge base (biologically secondary information) and uncovering the deep laws of nature less surprising and mysterious, since our mind itself might be structured and operate in the same way as information processing systems in the rest of nature. However, in contrast to most other natural information processing systems, humans need to be motivated and engaged in order to consciously and effortfully acquire biologically secondary knowledge they learn in educational institutions. This leads us to the need to consider the ability to engage in intentional activities in acquiring new secondary information patterns, an essential feature of human cognitive architecture as a higher-level natural information processing system (the intelligent natural information processing system).

Human Cognition as an Emerged Higher-Level Natural Information Processing System (Upward Extrapolation)

In line with the general logic of emergence of new features with evolution of new levels of natural information processing systems, the emergence of controlled, secondary processes on the level of human cognition could represent a qualitatively new evolutionary level of such systems. In most other natural information processing systems, transmitting and adopting information patterns appears to be the natural form of "learning" for which they are naturally, internally driven. In other words, this is the natural and only purpose of "learning." In human cognition, such natural forms of learning could only be applied to the acquisition of biologically primary knowledge. In contrast, the acquisition of secondary knowledge requires explicit, conscious, and effortful cognitive processes in working memory for which learners need to be externally motivated. In a way, acquiring secondary knowledge might be evolutionary analogous to artificial selection in biology, associated with selective human breeding of other species (e.g., pigeons and dogs). There is an explicit end goal to achieve as well as explicit intentional top-down manipulation of breeding prospects according to specific rules, even though the results occur through the same mechanisms as natural selection (such as sexual reproduction).

From this perspective, a more refined interpretation of evolutionary foundations of human cognition may be required by differentiating types of natural information processing systems based on the degree of involvement of explicit or non-automatic processes. This is in line with some recent suggestions to consider explicit intention to act (associated with actions to achieve specific goals, directly linked to consciousness) as an essential evolved characteristic of complex information processing systems (Liljenström, 2011; 2015). In the human neuronal system, this characteristic could be traced as related to willful acts corresponding to action programs for the achievement of specific goals with motivational and emotional aspects (Heisenberg, 2009; Ingvar, 1994; Wegner, 2003).

Therefore, in higher-level natural information processing systems that involve conscious mechanisms of adaptation to their environments, explicit intention to achieve specific goals is an essential part of the system's operation. The explicit intention to acquire new secondary information into the information store to effectively act in the changing future environment (either through random generation or through borrowing and reorganizing) could be defined as an additional principle of natural information processing systems emerging on higher levels of evolution (intelligent natural information processing systems), supplementing the five principles described above.

When applied to human cognitive architecture, this explicit intention to learn secondary knowledge principle has a clear and far-reaching implication for learning and instruction. Since virtually all formal learning focuses on biologically secondary knowledge, which requires conscious information processing in working memory, every learning task needs to be associated with specific activities aimed at setting the learner's explicit intention to acquire this secondary information. These activities may be aimed at externally motivating and engaging the learner, triggering curiosity, establishing gaps in the available knowledge base, activating any relevant available knowledge, etc.

In a recently proposed general theory of universal information processing systems, considered as systems of any nature that involve exchange of energy and matter interpreted in terms of learning and memory (and viewing natural information processing systems as a subset of such systems), Woolcott, (2020) suggested adding the principle of preparedness for learning as a major guiding principle for such systems. Interpreted as explicit preparedness or readiness to learn new secondary information, this principle has a similar meaning to the above explicit intention to learn principle. Applied to human cognitive architecture, this principle also assumes external motivation and cognitive engagement as essential parts of learning (e.g., in terms of Chi and Wylie's (2014) levels of cognitive engagement—from passive to active to constructive to interactive).

The explicit intention to learn principle, therefore, assumes the need for specific learner cognitive activities that have the goals to externally motivate and cognitively engage learners prior to acquiring biologically secondary knowledge through conscious processing in working memory. In most other natural information processing systems, these types of activities (or their analogies) are not needed. Human cognition has apparently evolved to a higher degree of complexity than other natural information processing systems (except, possibly, other primates and mammals that might have some limited similar capabilities, but we do not discuss them in this paper). In the human cognitive architecture, working memory evolved to deal with novel situations that exceed the capabilities of biologically primary mechanisms. In contrast to most other natural information processing systems, it provides the ability of inhibiting automatic execution of implicit, primary responses and replaces them with explicit, controlled, and effortful decision-making in working memory, inevitably generating cognitive load.

Thus, the most important feature distinguishing human (and perhaps some other species) cognition from virtually all other information processing systems is the presence of conscious, controlled processes in working memory that enable us to intentionally inhibit automatically executed environmental responses. This is exactly where cognitive load theory has the most to offer as an instructional theory, as these processes are constrained by the limitations of working memory. Therefore, such processes as random generation and direct borrowing (and reorganizing) may not fully explain the secondary information acquisition mechanisms in human cognition. The need for external learner motivation, focused on engaging learners in these instructional activities, implies that it is important to not only consider the learning activities themselves but also additional types of activities that have the goal to externally motivate and engage learners.

Implications for Educational Theories and Instructional Design

Adding an evolutionary perspective on human cognitive architecture to cognitive load theory has generated productive ideas about the nature of human cognition and revealed deeper reasons behind successful instructional methods. However, the general principles of natural information processing systems do not always directly and literally translate into immediately applicable instructional principles, especially when distinguishing features of higher-level systems such as human cognitive architecture that differentiate them from lower-level systems are not considered. By adopting the proposed dynamic, emergent-principle approach to the evolution of natural information processing systems, it is possible to view human cognitive architecture as a distinctively higher level in the evolution of natural information processing systems defined by its capability of controlled, explicit, intentional processing of information. An additional principle of the natural information processing systems of this level, defined as the explicit intention to learn principle, operationalizes this distinctive feature.

The explicit intention to learn principle stipulates some essential factors that influence human cognition and learning—such as motivational and affective factors of controlled information processing—in addition to other important factors that are substantiated by the other five principles described in the traditional version of the evolutionary approach to human cognitive architecture. It is feasible that the absence of such factors in the traditional evolutionary perspective on human cognitive architecture is a reason why, even though being central to the fundamental underpinnings of cognitive load theory, this perspective has been mostly viewed as auxiliary to the theory by most of the instructional psychology community.

According to the traditional version of the evolutionary approach to human cognitive architecture in cognitive load theory, human information processing system analogous to evolution by natural selection applies to learning secondary knowledge (e.g., see Sweller, (2022) for a recent discussion). Therefore, the suggested instructional procedures justifiably focus exclusively on secondary knowledge learning by explicitly using the instructional means stipulated by the borrowing and reorganizing principle. Activities that are considered as facilitating implicit primary learning, such as unguided exploratory or play-based activities, have diminished, if any, roles—mostly as supplementary instructional vehicles to enhance explicit instruction such as collaborative learning in groups, learner motor and physical activities (Paas & Sweller, 2012), and finger-tracing of instructional explanations (Hu, Ginns, & Bobis, 2015), using biologically primary contexts for presenting secondary information in instruction as a way to increase motivation and performance (Lespiau & Tricot, 2022a, 2022b), etc.

Adding explicit intention to learn to the basic principles of operation of intelligent natural information processing systems such as human cognitive architecture, and accordingly, including external motivation, engagement and affect as essential factors in the operation of such systems, makes it clear that conscious information processing in working memory and motivation or intent to get involved in such processing usually go hand-in-hand, thus expressing the fundamental interconnectedness of cognition and motivation. Accordingly, in the process of learning biologically secondary knowledge, learner activities might need to be intentionally designed to get learners motivated for and engaged in learning prior to acquiring the targeted secondary knowledge. The goals of such activities ("pre-instructional" goals) would essentially be to prepare learners for the following learning of biologically secondary knowledge ("instructional" goals) (Kalyuga & Singh, 2016; Plass & Kalyuga, 2019). The importance of preparing the learner for the actual learning tasks has been long acknowledged in education. For example, motivating the learner was considered as the first step of any instruction (Gagné, 1965).

From this perspective, the application of the borrowing and reorganizing principle as one of the main principles underlying the operation of human cognition (as well as most other natural information processing systems) may need some clarification. Traditionally, this principle is interpreted as providing a global-level underpinning for the effectiveness of explicit instruction for novice learners, as evidenced by the worked example effect in cognitive load theory. Kalyuga & Singh, (2016) suggested that even though worked examples and other forms of explicit instruction are indeed the most efficient ways for novice learners to acquire new domain schemas, this is only the case if this knowledge acquisition is in fact the intended goal of learning. However, if the intended goal of a learning activity is different (e.g., one of the above "pre-instruction" goals), other types of instructional means could achieve it more efficiently—according to the newly added explicit intention to learn principle of the operation of intelligent natural information processing systems.

The productive failure and invention learning instructional approaches (Kapur, 2008; 2014; Loibl, Roll, & Rummel, 2017; Schwartz & Martin, 2004) provided some relevant empirical evidence for the instructional feasibility of such alternative learning activities (e.g., exploratory problem-solving prior to explicit instruction in canonical solution procedures) for achieving corresponding "pre-instructional" goals. Learner engagement in a guided social play or exploration (traditional means of primary learning) could also facilitate cognitive mechanisms necessary for effective learning secondary knowledge in a more motivated and enjoyable way, thus bridging the "evolutionary mismatch" between the activities that support primary learning and those needed for secondary learning (Bjorklund, 2022; Geary, 2008).

Adding explicit intention to learn to the set of principles guiding the operation of intelligent natural information processing systems such as human cognition highlights the role of intentionality in human learning in general. For example, in their theory of cultural learning, Tomasello, (2016) and Tomasello et al., (1993) proposed the distinguishing processes of human cultural learning (learning through another individual and her/his perspective on the situation, like how to select a problem-solving strategy in a specific situation) from processes of social learning that humans to a significant degree share with primate species (learning because of or from another individual, like finding water to drink or fruits to eat). This distinction might be considered analogous to learning secondary and primary skills correspondingly in evolutionary educational psychology. From this perspective, cultural learning (analogous to learning secondary information) “depends on how the learner understands the individual from whom she is learning, for example, as an intentional agent who both pursues goals and attends to things relevant to those goals” (Tomasello, 2016, p. 643). The theory considers intentionality in three types of cultural learning—the imitative learning (the learner intends to learn by observing what another individual intends to do), instructed learning (someone else intends to teach the learner, and the learner intends to learn through that instruction), and collaborative learning (two or more individuals are working together and intend to learn through one another). This classification may provide a framework for further investigation of the role of intentionality in conjunction with motivational factors in learning secondary competencies.

The addition of motivation or intent to cognitive psychology models dealing with information processing systems in general, and the combination of cognitive load theory and motivation in particular, has not yet produced significant findings, for example, an evidence-based list of effective motivation-inducing procedures supported by randomized, controlled trials similar to the way in which cognitive load theory effects have been generated. Some existing in this area studies consider increased motivation (and the resulting enhanced performance) as a consequence of reduced cognitive load rather than a direct primary cause of enhanced performance without the mediating role of cognitive load (e.g., Feldon et al., (2018, 2019); see also Martin, (2023) for a review of some developments in this area). Adding explicit intention to learn to the basic principles of operation of human cognitive architecture, and including external motivation, engagement and affect as essential factors in this architecture, thus postulating the fundamental interconnectedness of cognition and motivation on the evolutionary level, may have the potential to break the continual failure of attempts to add motivation as causing performance changes in association with cognitive load theory.

Notwithstanding the outlined differences between the human cognitive architecture as an intelligent natural information processing system and other information processing systems in nature, the extrapolations in both directions explored in this paper still supported their important similarities underpinned by the common five evolutionary principles formulated within the traditional evolutionary perspective. One of the most crucial characteristics shared by all natural information processing systems, including human cognitive architecture, is the major role of the information store in their operation (the information store principle applies to all of them, down to the lowest-level systems in the above downward extrapolation). All such systems can successfully adapt to their environment by making it familiar, i.e., by acquiring relevant information patterns in the store (in the case of human cognition, organized generic knowledge structures in long-term memory). The information patterns in that store guide the behavior of the system by making the external environment familiar, thus removing limitations on information processing and changes to the store, thereby reiterating the nature of evolved human cognitive architecture as fundamentally knowledge-based system.

The operation of this system is dependent on a massive store of organized knowledge structures of generic nature (schemas) in long-term memory that allow us to function successfully in very complex environments. The expertise reversal effect in cognitive load theory (Kalyuga, 2007; Kalyuga et al., 2003; Kalyuga, Rikers, & Paas, 2012) could be directly related to this role of knowledge in human cognition, reflecting the role of information store in natural information processing systems. According to this effect, instructional procedures and activities that are effective for novice learners could be ineffective for expert learners, and vice versa. For example, providing instructional guidance in problem-solving procedures could inhibit expert learners' performance. From the evolutionary perspective, the expertise reversal effect indicates the role and strength of experts' knowledge base that resists interference from external information (which is essentially becomes redundant) as expressed in the reduced levels of experts' performance in cases of such interference in comparison with cases without it, i.e., when experts rely only on their own available knowledge base.

From the traditional evolutionary perspective, experts' performance in their area of expertise is ideally based on only two principles—information store and environmental organizing and linking principles—with the remaining three principles suppressed: the available knowledge structures directly guide experts' performance without working memory limitations, random search, or external information to borrow. Any factors or activities that cause activation of any other principle could inhibit the experts' performance resulting in the expertise reversal effect. A similar phenomenon could be potentially expected for the proposed new explicit intention to learn principle: it could also be suppressed while experts act in their area of expertise, and any additional activities designed to foster motivation and engagement could inhibit experts' performance. This form of the expertise reversal effect needs to be experimentally investigated in future studies.

In summary, this paper suggests that while the basic information processing principles used by cognitive load theory apply in attenuated form even to non-organic systems associated with physics and chemistry, at the level of psychology, including educational psychology, they may require adding an additional principle to account for motivation and intention. Accordingly, the updated complete set of six principles describing the operation of intelligent natural information processing systems, such as human cognitive architecture, includes the randomness as genesis principle, the borrowing and reorganizing principle, and the explicit intention to learn principle (these three principles relate to the acquisition of information), the narrow limits of change principle and the information store principle (these two principles relate to the processing and storing of information), and the environmental organizing and linking principle (which relates to the use of the stored information).

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