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DESIGNING FOR SCHEMA DEVELOPMENT: INTEGRATING LEARNING THEORY AND NEUROSCIENCE

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INTRODUCTION

With modern advances in neuroscience, it has become possible to identify and track brain functions related to learning as never before. However, while this may expand our understanding of how learning occurs, it does not mean that traditional learning theories such as cognitivism, constructivism, and socio-constructivism have lost their relevance.

In particular, neuroscience has posited some possible physical mechanisms for the cognitive framework of schema theory. Schema theory, originating in the work of Bartlett (1932) and further developed by Piaget (Wadsworth, 1971) and cognitive psychologists, proposes that knowledge is organised into interconnected constructs that support interpretation, memory, and prediction (Bein & Niv, 2025; Greve et al., 2019).

This article argues that the schema concept provides a useful integrative framework for learning design. Drawing on educational theory and recent neuroscientific evidence, it proposes that learning designers can intentionally support schema activation, development, modification, and transfer through carefully designed learning experiences.

First, a note about terminology: cognitivism focuses on learning through mental processing and creating memory structures, while constructivist and socio-constructivist perspectives on learning emphasise meaning-making through experience and social interaction, respectively. Together, these perspectives offer complementary insights into schema learning, as we will describe below.

WHAT IS A SCHEMA?

A schema is a figurative concept used to refer to an associative network that organises, categorises, and interprets information about an aspect of the world we live in. You can think of a schema as a folder within a filing system that stores all concepts and memories related to that aspect. A schema might be of a process or procedure (for example, checking in for a flight), or of a tangible concept (for example, having a dog as a pet). Your schemata (plural of schema) allow you to group related information and retrieve this information when faced with a familiar or unfamiliar situation, to generate expectations that predict and make sense of novel experiences. Schemata are adaptable; they can incorporate fitting information (assimilation) and non-fitting information (accommodation) (Armelin et al., 2017; Wadsworth, 1971). Therefore, "schema learning" has been conceived as the process of first activating, then modifying schemata.

Schema components are stored as neural assemblies called engrams that are the smallest units of memory or learning (Andonovski, 2024; Guskjolen & Cembrowski, 2023). While schemata are figurative constructs, an engram is a physical cluster of neurons connected by synapses. Initial learning takes place in the hippocampus, laying down engrams in this brain region known to be important for memory. The engrams of a schema remain connected, while distantly located across different brain regions as "mental files" (Andonovski, 2024). For example, a schema for "dog" might include the sound of barking (stored in the auditory cortex), the appearance of a dog (stored in the visual cortex), and associated memories of interactions with dogs (stored in other brain regions involved in long-term memory). These engram neurons are scattered across distant brain regions like constellations in the night sky. Emerging evidence shows that initial hippocampal engrams are reactivated during memory retrieval (Guskjolen & Cembrowski, 2023) and orchestrate the activation of more distant engrams in the broad schema, allowing the brain to reconstruct the full concept from distant neural traces (Andonovski, 2024; Reijmers et al., 2007).

Understanding this relationship between schemata and their physical substrates helps to narrow the gap between theoretical predictions made by cognitive psychologists and tangible advances made by neuroscientists. The process by which entirely new schemata are formed remains incompletely understood. Keeping this in mind, in this article we attempt to bring together schema theory and neuroscientific developments to explain how learning design strategies can support learning through schema development. First, we consider how to strengthen new schemata; then how to activate schemata, and finally how to change existing schemata.

DESIGNING FOR SCHEMA STRENGTHENING

Learning takes place when new information comes into the working memory (a short-term cache that is limited in capacity), and is able to be encoded, which means that it is transferred to long-term memory. Importantly, encoding does not simply mean storage: it means integration into a connected schema (Greve et al., 2019; van Kesteren et al., 2012). Schemata are constructs within long-term memory; they are not synonymous with long-term memory itself but rather represent the way knowledge is organised and interconnected. In order to integrate the new information, a relevant schema needs to be retrieved from long-term memory into working memory. This process of retrieving and encoding has a number of implications for learning design. First, it is important not to overload the working memory by introducing too much new information at once. This relates to cognitivism's well-researched cognitive load theory (Sweller et al., 2019), whose premise is that working memory capacity is relatively fixed for any given individual and that cognitive effort depletes working memory. Second, connecting new information to existing schemata is helpful for long-term retention. This connection can be achieved through designing activities that require learners to explain, compare, or justify.

Third, new learning that is not yet well-established within a schema needs to be consolidated. This is a process in which the repeated retrieval of the information item reactivates the relevant schema and thereby strengthens neural connections throughout the corresponding engram (Oakley, 2026; van Kesteren et al., 2012). A well-established cognitivist strategy for strengthening and consolidating schemata is spaced practice, whereby learning and retrieval opportunities are distributed over time rather than massed together (Yang et al., 2025).

One learning design approach favoured by cognitivists (and many constructivists) that can combine cognitive load management, retrieval practice, and spaced learning is direct instruction, shown in

Figure 1. Direct instruction includes active learning, which is strategically interspersed with more traditional knowledge transfer ("teacher-led learning").

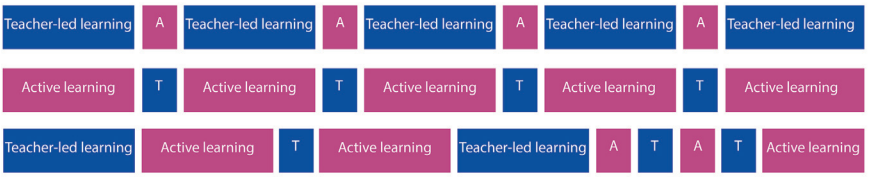


Figure 1. Direct Instruction has advantages of both teacher-led learning (fast, direct knowledge transmission) and active learning, which is more engaging and allows for practice of the new skill, concept, or knowledge (for example, cognitivist approaches of retrieval and rehearsal).

DESIGNING FOR SCHEMA ACTIVATION

There is general agreement among cognitivist and constructivist educators and researchers that knowledge is actively constructed in the mind of the learner by building on their prior knowledge. The role of the teacher is often to activate relevant prior knowledge, conceptualised here as schemata. Activating prior knowledge before learning facilitates subsequent memory consolidation (Brand et al., 2025). Schemata can be activated when a familiar cue is provided, such as related information in that schema (Brand et al., 2025). Neuroscientists have shown that this triggers activation of the same neurons that encoded that memory; that is, the initial engram neurons located in the hippocampus (Reijmers et al., 2007). Over time, consolidation of learning can extend these memories from the hippocampus, where they can be found in cortical regions of the brain (Hebscher et al., 2019). Guskjolen and Cembrowski (2023) further explain how activating relevant schemata occurs in cortical regions, first through the hippocampal engram neurons involved in the initial memory encoding. The hippocampal engram neurons in turn re-excite cortical engrams in the broader schema, which are largely stored in the medial prefrontal cortex and other cortical regions. This has been likened to an indexing function of the hippocampus, which explains why contextual cues are so effective at triggering schema activation: the hippocampus uses such cues to locate and retrieve the relevant schema, so bringing it into working memory (Guo et al., 2023; Guskjolen & Cembrowski, 2023).

How, then, can we design for schema activation? The important principle is to retrieve familiar knowledge or skills before building new ones. However, there is still discussion in the literature about how much prior knowledge needs to be elicited to prime the system for learning without overwhelming learners (Brand et al., 2025). From their studies of teaching maths to school students, Brand and colleagues conclude that "effective preparation for instruction is not about how much relevant prior knowledge is activated, but is about striking the right balance: too little may leave students unprepared, too much can be overwhelming, but just the right amount prepares students optimally for learning" (Brand et al., 2025, p. 1654). Establishing a practice of reviewing foundational learning before embarking on more advanced learning is a solid strategy that will activate and strengthen relevant schemata.

Questioning offers a further route to schema activation. A well-formed question can help direct learners' attention and define the scope of what is being considered, prompting them to retrieve relevant prior knowledge structures into working memory (Oakley et al., 2026). By narrowing the field of consideration in this way, questioning may provide a framework for interpreting new information and support deeper understanding.

DESIGNING FOR SCHEMA MODIFICATION

Schemata are not fixed structures, but are constantly being modified as new information comes to hand. In Piaget's early work, he described how they can be updated with fitting, congruent information ("assimilation") and also incorporate contrasting or incongruent information by "accommodation" (Wadworth, 1971). This dichotomy is explored by Greve and colleagues (2019) who propose distinct mechanisms: assimilation occurs at the encoding level, through reactivation and strengthening of existing schema, as described earlier. Accommodation occurs at a post-encoding level through prediction and error detection (Greve et al., 2019).

Neuroscientific evidence summarised by van Kesteren et al. (2012) shows that presenting new information that violates a schema activates the medial prefrontal cortex. They propose that this brain region plays a role in detecting whether new information is congruent with existing schemata located in other parts of the brain's cortex. Armelin et al. (2017) found the hippocampus also plays a vital role in accommodation. The emerging process relies on a prediction-error mechanism: first learners retrieve an existing schema, then they use it as a neural template to make a prediction; any mismatch between the prediction and the reality represented by the new information triggers schema revision (Bein & Niv, 2025).

Bein and Niv (2025) hypothesise that schema learning aligns well with the computational model of "reinforcement learning," for instance in how we update existing schemata by detecting prediction errors. Reinforcement learning, when applied analogously to human rather than machine learning, relies on experience: a prediction error is detected when actual experience differs from the predicted experience. When an experience cannot be adequately explained by any existing schema, and is sufficiently different from similar observations, the brain may create a new schema (Bein & Niv, 2025). For example, an outlier might become an entirely new schema, or might be assigned into the 'exceptions-to-the-rule' schema. This fits with Piaget's initial conception that accommodation involves both the creation of new schemata, and the modification of old schemata (Wadsworth, 1971), the biological mechanisms for which are now starting to be better understood.

The recognition of discrepancies caused by prediction errors can produce the familiar "Aha!" experience associated with lightbulb moments of new learning. Aha! moments, comparable to Piaget's "cognitive disequilibrium" (Oakley et al., 2026, p. 18), are likely to generate the productive dissonance necessary for schema revision. These moments of insight result in the release of dopamine and norepinephrine (Tik et al., 2018). As well as supporting memory formation, these consequent neurochemical responses are associated with positive affect and may contribute to our intrinsic motivation for learning.

This process of accommodating new information and insights raises the question of how learning designers can facilitate the updating of schemata. Experiential learning strategies are particularly effective at supporting accommodation because they involve concrete experience and require learners to reflect. In light of the above, we propose additionally requiring learners to make and test predictions, making mismatches explicit, followed by opportunities to reflect on mismatches between new and prior knowledge.

A socio-constructivist perspective acknowledges the importance of collaboration and social interactions. Learners may re-negotiate and co-construct meaning, or "arrive at self-chosen positions to which they can commit themselves, while realising the basis of other views with

which they may disagree" (Cunningham, 1991, p. 14). Designing for socio-constructivist learning can support adult learners to recognise multiple perspectives, providing opportunities to adapt their schemata. Collaborative learning can accelerate this process further: observing peers' different predictions and choices helps learners recognise discrepancies they might not have noticed independently.

DESIGNING FOR TRANSFER OF LEARNING THROUGH SCHEMA APPLICATION

Transfer of knowledge is vital in tertiary education where our learners will need to transfer and apply newly acquired knowledge to future, unknown problems. The classical cognitive view of transfer assumes that context sits alongside, or can be separated from, the initial learning of content (Nokes-Malach & Richey, 2015). However, constructivists posit that new knowledge is "embedded" within the context in which it is learnt: that is, learning is said to be "situated" within contexts (Brown et al., 1989; Lave, 1988). In most tertiary institutions, learning needs to take place in classrooms and lecture theatres; therefore, transfer of learning to future professional contexts is essential.

Nokes-Malach and Richey (2015) describe teaching strategies for effective transfer through comparison; that is, asking learners to compare and contrast case studies by detecting common structural features, while ignoring distracting differences. This creates an "abstract schema" that allows learners to solve problems with similar surface features (Nokes-Malach & Richey, 2015, p. 5).

The learning design approach favoured by constructivists is known as "anchored instruction," which includes, but is not limited to, framing the learning around a problem to be solved (Li et al., 2023). If we apply a schema lens to anchored instruction, we first draw on the concept of a schema as a neural template that captures common structural features across experiences (Bein & Niv, 2025). The more abstract and flexible the schema becomes, the more readily it can support generalisation to novel situations. For the learning designer, there are numerous ways that transfer of learning can be promoted, such as contrasting cases, varied contexts, interdisciplinary projects, simulations, and authentic assessment. Thus, the learner repeatedly retrieves and adapts the same theoretical schema in different situations, making transfer more likely.

CONCLUSION

Schema development provides a useful integrative framework for learning design, bringing together insights from cognitivism, constructivism, and socio-constructivism. While each theory offers a different perspective on how learning occurs, all contribute to the activation, development, modification, and application of schemata. Recent advances in neuroscience have begun to reveal the biological mechanisms that may underpin these processes, providing additional support for many established educational practices.

What, then, does a schema-informed approach to learning design look like? First, it promotes activation of schemata by helping learners identify and retrieve relevant prior knowledge. It encourages the efficient development and consolidation of schemata through a combination of direct instruction, experiential learning, and spaced practice. Attention is paid to cognitive load so that working memory can effectively connect new information to existing knowledge structures. The dynamic nature of schemata is acknowledged through opportunities for questioning, prediction,

comparison, and the recognition of dissonance, all of which support schema modification. Finally, transfer of learning is promoted through authentic, varied, and collaborative learning experiences that encourage learners to apply and adapt schemata across contexts.

Effective learning design should therefore:

1. Activate prior knowledge.
2. Connect new information to existing schemata.
3. Manage cognitive load.
4. Provide retrieval and spaced practice.
5. Create opportunities for prediction and prediction error.
6. Support transfer across contexts.
7. Facilitate collaborative refinement of schemata.

Contemporary neuroscience does not replace learning theory; rather, it provides biological explanations for why many established learning design approaches remain effective.

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