science of learning portal

Effective teaching and its relation to our scientific understanding of learning

Has the time come to introduce a scientific understanding of learning into teacher education? What might this look like?

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Executive summary

- A simple framework for thinking and talking about classroom learning might consist of: **engagement** for learning, **building** of new knowledge and understanding, and **consolidation** of learning.
- In teacher training and development**, we now have sufficient knowledge to begin explaining and promoting core classroom learning practices using scientifically informed concepts of learning**.
- This can:
  - help increase the **focus on learning**
  - provide the first **defence against myths**
  - provide an authentic **foundation for insight and practice**
  - inform classroom **implementation of reform**
  - support professionalism by **empowering teachers** with a scientific understanding of teaching and learning

A scientific focus on learning

On a global level, while many countries have increased their spending on education and increased the number of children attending school, the goal of ensuring the quality of provision has been more elusive[1]. For example, around half or more of children completing primary schooling in many countries (including India, Bangladesh, Pakistan, Kenya, and Tanzania) cannot read even the simplest texts or perform simple arithmetic. One economist estimates that, at the current rate of progress, it will be well over 100 years before students in developing countries can produce similar results in science exams as today's students in developed countries[2]. In the last 1-2 decades, governments, scientists, and educators have become increasingly interested in developing a 21[st]-century education system supported by more concrete evidence of how we learn. The different names attached to this interdisciplinary work include "Mind, Brain, and Education," "Science of Learning," "Neuroeducation," and "Educational Neuroscience." These names reflect how neuroscience, psychology, genetics, and many other disciplines are becoming increasingly relevant for our emerging scientific understanding of learning.

There are at least three practical ways in which a scientific understanding of learning can benefit teachers and students in the classroom:

1. *Neuromyths*

    It appears self-evident that a more scientific understanding of learning amongst teachers would help dissipate the many *neuromyths*, or unscientific ideas about the brain, that are prevalent in education. Many neuromyths are associated with poor practice, and they make a strong argument for including a basic understanding of the scientific principles of learning in teacher training and development[3,4].

    Despite increasing public interest, the public's awareness of neuroscience is never likely to keep pace with our accelerating growth in understanding the brain. This suggests the problem of neuromyths is likely to grow, at least in countries where teacher training and development continue to omit a scientific understanding of learning. At present, much of the information that reaches teachers about the brain is from the public media[5], making it impractical to consider "protecting" teachers from ideas related to neuroscience—even if this could be morally justified.

2. *Interventions*

Scientific research is applying new technologies and ideas to uncover fresh insights into how we learn. Neuroimaging, for example, allows us to study brain function while adults and children are acquiring skills such as mathematics and reading. By understanding underlying learning processes, we can better develop new interventions to enhance children's achievements. There have been several experimental studies indicating promising ways to improve classroom learning. In some cases, we have scientifically based ideas for interventions well-tested in classrooms and shown to provide benefits. These include the spacing out and interleaving of learning sessions, testing regimes, and new reading approaches. Others have shown great promise under controlled laboratory conditions or small-scale educational applications, such as interventions based on exercise, sleep, or on providing particular schedules of reward. Large-scale trials are now underway in schools that are focused on these and other ideas[6].

3. *Informing the day-to-day practice of a teacher*

Perhaps, however, the most significant benefit of underpinning education with a scientific understanding of learning may be its influence on the day-to-day practice of teachers. Ultimately, most would agree that a key determinant of a student achieving his or her potential is the quality of their teacher's practice. Can a scientific understanding of learning help with this quality?

This brief will particularly focus on this last issue. It considers the readiness of our scientific knowledge to explain and provide insight into core principles in teaching that have been established elsewhere as benefiting learning outcomes.

Teaching quality and the understanding of learning

A recent review[7] of the international literature identified six attributes of good teaching, of which only two were supported by the strongest evidence:

1. *(Pedagogical) content knowledge (Strong evidence of impact on student outcomes)*

The most effective teachers have deep knowledge of the subjects they teach. When teachers' knowledge falls below a certain level, it is a significant impediment to students' learning. As well as a strong understanding of the material being taught, teachers must also understand the ways students think about the content, evaluate the thinking behind students' own methods, and identify students' common misconceptions.

2. *Quality of instruction (Strong evidence of impact on student outcomes)*

Quality of instruction includes elements such as effective questioning and use of assessment by teachers. Specific practices like reviewing previous learning, providing model responses for students, giving adequate time for practice to embed skills securely, and progressively introducing new learning (scaffolding) are also elements of high-quality instruction.[7]

Knowledge of learning processes cannot substitute for knowledge of the topic being taught, but the definition of "pedagogical content knowledge" above includes both. It makes specific reference to understanding how students think about the content. In terms of "quality of instruction," the Coe et al. (2014) report emphasizes elements such as effective questioning and use of assessment by teachers. High-quality instruction is considered to include specific practices, such as reviewing previous learning, providing model responses for students, giving adequate time for practice to embed skills securely, and progressively scaffolding new learning. The report also concludes there is moderate evidence for the effects of classroom climate and management, and some evidence for the impact of teacher beliefs and professional behaviors.

In short, current research demonstrates that student outcomes are significantly influenced by the understanding of the teacher and his/her evaluation of student thinking and learning. On this basis, informed consideration of students' learning processes may be key to improving outcomes. Also, although specific practices can be prescribed to teachers, their effective implementation is likely to rely on understanding how they are supposed to operate. Simply identifying and prescribing "what works" may not be sufficient for ensuring the success of top-down educational reform. Indeed, rather than implement a "one size fits all" approach, teachers continuously adapt their teaching to the learner and the context, applying their own theory about their students' mental processes and considering how they can influence these processes to scaffold learning[8]. It has been said that trying to teach without understanding learning is a bit like trying to fix a washing machine without knowing how it works[9]. Of course, teachers support learning behaviors that are much more complex than a washing machine. On this basis, the literature reviewed by Coe et al. (2014) and others support the notion that students benefit from teachers who understand learning processes.

A scientific understanding of learning is also particularly important for ensuring educational reform in a culturally diverse world. Respect for cultural diversity is emphasized by the Education-2030 targets (Target 4.7 [10]), and attention to diversity requires teachers to adapt teaching strategy. Indeed, teachers' response to top-down reform is itself a process of cultural adaptation[11], with practitioners integrating their own reflections, attitudes, and behaviors with the recommended changes[12]. In other words, teachers may take what they are given, but they will make it their own. This undermines any sense that a purely prescriptive approach to educational reform can ever be entirely successful. The success of reform will always rely, in large part, on teachers being sufficiently empowered with an understanding of learning. They will then be better positioned to interpret appropriately the processes by which learning practices are supposed to achieve their goals and to understand how these ideas may be adapted for their own students while preserving these processes.

The neuroscience of learning—with synaptic plasticity as the basis of learning and memory—can provide an inherently proactive and hopeful message. There is already some empirical evidence to suggest that teacher development within the neuroscience of learning can motivate teachers and their students to attend and participate more in the learning process. After receiving one such programme of development, secondary school teachers were more self-aware of how their own teaching behaviors had the capacity to change students' brains as students experienced, modeled, utilized, and constructed their own knowledge[13]. When awareness of the brain's plasticity is passed on to students, this can improve student awareness of their role in constructing their own abilities, which has been shown to improve their growth mindset and resilience in their academic studies, reduce dropout rates[14], and improve self-concept and academic outcomes[15].

What sort of knowledge might benefit teacher understanding, teaching quality, and student outcomes?

Given the above justification for all teachers to know more about the science of learning, it seems evident that a Science of Learning curriculum should be:

- able to provide a basis for insight into how students think about and acquire learning content
- able to provide insight into the processes underlying specific practices associated with effective teaching
- aligned with current state-of-the-art scientific understanding
- be accessible to educators who are not specialized in science, and who work in a range of contexts (e.g., age groups, topics, cultures)

Communication across the gap between neuroscience and education

Although the potential advantages are many, making scientific knowledge accessible to those who are not specialists in science is always challenging. There are inherent dangers of "boiled down" messages about the science leading to misinterpretations and poor practice in the classroom[4]. On the other hand, of course, messages that are too complex in their content or communication may communicate little or also be easily misunderstood. It is also possible that the scientific messages can become overly biased by the present preoccupations of the scientific field or the professional aims of scientists, leading to statements that are not as educationally relevant or as appropriate as they might be.

The language and terms of science regarding learning can also be quite different from those used by educators. Some words such as "attention" and even "learning" can have quite different definitions in the two domains[16]. In light of this, a simple theoretical framework is needed for classroom learning that is appropriately scientifically and educationally meaningful, so helping to map concepts helpfully across education/public domains and the sciences of mind and brain.

A simple framework for classroom learning

A simple framework for thinking and talking about learning in the classroom might comprise three categories of the underlying process, all of which can actively involve the teacher: (1) *engagement for learning*, (2) *building of new knowledge and understanding*, and (3) *consolidation of learning*. These are broad categories intended to help structure an understanding of the relevance of scientific insight for classroom practice. They attempt to minimize confusion of scientific and educational terms where these are not equivalent. For example, *engagement* is an educational term that is not often encountered in the scientific literature—it is not constrained by a scientific definition. A range of scientific aspects of learning can be drawn together under this broad educational heading. These include new insights into emotional processing and attention while allowing the discussion to consider these aspects as distinct but potentially related. The heading *building of new knowledge and understanding* might include Vygotskian/Bruner constructivist notions of an expert scaffolding a novice's thinking[17], but could also include more Piagetian approaches that involve, for example, exposure to cognitive conflict[18]. *Consolidation of learning* has appropriate and helpful scientific associations with memory consolidation processes, but might also include effects of educational practice such as automatization.

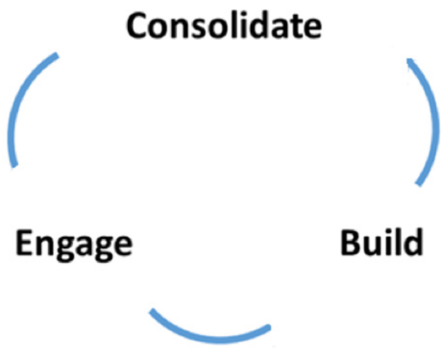

Figure 1: Consolidate, Build, Engage

Learning can be assumed to begin with engagement, and consolidation of new content is only likely after it has been initially represented in the student's mind/brain (i.e., following the building of new knowledge and understanding). Therefore, these elements might be represented as operating in the sequence of *engage* -> *build* -> *consolidate*. However, it is also possible to consider some movement in the opposite direction (e.g., finding ways to engage children in practice that consolidates freshly learnt ideas). Also, different parts of a learning experience might involve processes in more than one category occurring simultaneously. Therefore, these categories of the learning experience are better represented as in Figure 1, with the possibility of moving freely between them.

The science of engagement, building, and consolidation

Scientific research that is relevant to each of these three areas has been briefly reviewed in preceding briefs[19,20,21] but the executive summaries of this review are reproduced in Table 1 for convenience:

ENGAGE	1. Every learner's brain is unique, and students differ in what most engages their attention and the extent to which they can control their attention, making it important for teachers to monitor engagement and vary approach accordingly.
	2. Teachers employ many strategies known to stimulate an "approach" response in the brain. These include rewards such as praise and tokens acknowledging achievement, novelty, provision of choice, and shared attention. The anticipation and receipt of rewards can release neuromodulators capable of improving attention and memory.
	3. In contrast, fearfulness can avert attention, and anxiety can diminish a student's learning by reducing the brain's ability to process information[22].
	4. Engagement can be diminished by teachers' and students' notions that there is a fixed limit to what a student can learn. But the brain is plastic, and both teacher and student have an important role in constructing its function, connectivity, and structure.
BUILD	5. Being aware of students' prior knowledge is important for a teacher because this is the foundation on which the students' new knowledge will build.
	6. Teachers can help students think meaningfully about new ideas by encouraging them to make connections with their prior knowledge. This is important for children, whose neural circuitry for this connection-making process is still developing. Differences in learning and development result in diverse individual differences.
	7. The brain is multisensory. Clear, concise instruction using all the senses, embodiment, action, and encouraging links between different representations, all aid the communication and student understanding of new knowledge.
	8. Our mirror neuron system helps us read each other's minds. Gestures and faces communicate knowledge and emotions both consciously and unconsciously, supporting the teacher's transmission of concepts, confidence, and enthusiasm.
CONSOLIDATE	9. Practice and rehearsal of freshly learnt knowledge cause it to become automatically accessible. This frees up the brain's limited capacity to pay conscious attention, and so be ready for further learning.
	10. Answering questions, applying knowledge in new situations, discussing it with others, or expressing it in new forms consolidate our learning by helping us store it in different ways—making it easier to recall and apply it.
	11. Sleep plays an important role in the processes that consolidate our learning. A good night's sleep helps attend to today's learning and makes yesterday's learning more permanent.

Table 1. Scientific concepts identified with potential relevance to core teaching practices

Insight into the "how" of specific practices associated with effective teaching

To illustrate the potential helpfulness of a scientific understanding of learning, the explanatory power of the above insights will be examined regarding a selection of specific practices associated with effective teaching. The key questions are: (a) whether the particular practices can be explained in terms of this simple neurocognitive model of classroom learning, and (b) whether this deeper understanding of learning can potentially contribute to the implementation of the practice. Examples were drawn from two issues of the IAE-IBE Educational Practices Series, where practices are often referred to as "principles"[23,24]. Note that these were selected based on their generality (i.e., they were general in their potential application, and not tied to specific topics such as literacy or numeracy).

Example 1: Classroom instruction and teacher emotions

The seventh principle provided in IAE-IBE's "Emotion and learning" in the Educational Practices Series[24] is "Provide high-quality lessons and make use of the positive emotions you experience as a teacher." This is justified on the basis that the "motivational quality of instruction influences the perceived value of learning, thereby promoting enjoyment and reducing boredom." Regarding teacher emotions, the report advises that "teachers should take care to show the positive emotions they feel about teaching and the subject matter, and make sure that they share positive emotions and enthusiasm with their students."

As part of the communication underpinning the support of students' thinking, a similar issue is considered under *Build* in Table 1:

- Our mirror neuron system helps us read each other's minds. Gestures and faces communicate knowledge and emotions both consciously and unconsciously, supporting the teacher's transmission of concepts, confidence, and enthusiasm.

This perspective has a slightly different emphasis that has implications for practice. It highlights the likely transmission of the teacher's genuine emotion irrespective of their careful effort. This highlights the need for the teacher to maintain an active interest in the topics they teach, ensuring communication of genuine competence and enthusiasm.

Example 2: Guide student practice

The fifth principle of instruction provided in IAE-IBE's "Principles of instruction" in the Educational Practices Series[23] is "Successful teachers spent more time guiding the students' practice of new material."

The review points out that more successful teachers check for student understanding, provide additional explanations and examples, and provide sufficient instruction for students to practice independently without difficulty. This notion of identifying where students' understanding becomes limited (i.e., the current limit of their prior knowledge) and providing just enough support for them to move on as independently as possible reflects scientific understanding that:

> *Teachers can help students think meaningfully about new ideas by encouraging them to make connections with their prior knowledge. This is particularly important for children, whose neural circuitry for this connection-making process is still developing. Differences in learning and development will result in diverse individual differences within any class.*

This understanding emphasizes the need to consider individual progress and differences in the rate of progress, and that different students will require different levels of scaffolding. Understanding the how/why of guidance may help practices of less successful teachers who, as highlighted in the report, provide fewer explanations, pass out worksheets, and simply tell students to work on the problems.

Example 3: Daily review

The first principle of instruction provided in IAE-IBE's "Principles of instruction" the Educational Practices Series[23] is "Daily review can strengthen previous learning and can lead to fluent recall." Review is recommended because practice helps us recall concepts and procedures effortlessly and automatically, and is linked to higher achievement scores. The report points out that the most effective teachers in studies of classroom instruction understand the importance of practice and begin their lessons with a five- to eight-minute review of previously covered material.

In the report, daily review is considered chiefly in terms of working memory. This explanation echoes the discussion regarding consolidation:

- Practice and rehearsal of freshly learnt knowledge cause it to become automatically accessible. This frees up the brain's limited capacity to pay conscious attention, and so be ready for further learning.

Scientific research has added to our understanding of why testing may be advantageous for learning:

- Answering questions, applying knowledge in new situations, discussing it with others, or expressing it in new forms consolidate our learning by helping us to store it in different ways—making it easier to recall and apply it.

There are, however, further justifications for daily review, when considered from a perspective that includes the whole learning process. In terms of supporting students to build their knowledge and understanding:

- Being aware of students' prior knowledge is important for a teacher because this is the foundation on which the students' new knowledge will build.

Daily review may also be important, therefore, to identify students' prior knowledge (which may be different than the knowledge that has been taught) and so indicate where and how the building of new knowledge might resume (e.g., where additional support is needed).

A scientific understanding of the learning processes underlying daily review can also contribute to its implementation as in the following examples:

- Daily review might benefit from using novel contexts and examples for testing.
- Daily review might pay particular attention to knowledge that will soon be built upon.
- Given the role of sleep in consolidation, morning review of the previous day's learning may be more meaningful for informing the teacher than end-of-day review of the same day's learning.
- Review may benefit from an environment that diminishes anxiety and attracts the full engagement of the student (e.g., praise, game-like rewards).

Broader mapping of the extent to which scientific concepts can underpin core teaching practices

Science concepts were mapped to each of the 10 practices/principles identified in "Effective instruction" and "Emotions and learning" to determine the extent to which the identified scientific concepts could provide insight into core teaching principles. A scientific concept was considered to relate to the principle when it offered insight into how/why the principle works and/or might be implemented (see Table 2).

Discussion

Coverage of principles/practices was almost, but not entirely, comprehensive. Principle 4 in "Principles of instruction" was "Provide models." No basis for its underlying processes could be identified amongst the scientific concepts. Discussion of the principle included reference to guiding the student and also encouraging independent practice. These ideas could be supported by the scientific principles identified—and this is evident in the mapping of two other principles in this issue related to these references (Principles 5 and 9). However, Principle 4 made much of "worked examples" and the possibility of mixing worked examples and problems to solve. As with other principles in this text, this is well-supported by educational research as being an effective approach. The author, however, finds it difficult to explain the processes underlying this efficacy based on current scientific understanding of learning. This may highlight how the present type of mapping exercise may be useful in exposing areas where further scientific research might reveal some scientifically interesting and educationally valuable insight.

Also, a mapping was made when a scientific concept provided insight into how/why the principle generally works and/or might be implemented. That does not mean that **all** aspects of the principle/practice were necessarily explained by the scientific concepts identified.

It is also important to recognize that the extent of evidence underlying the scientific concepts is variable and often constrained to laboratory experiments. In most cases, the relevance of scientific research to classroom learning is itself a reasoned hypothesis that demands further testing. For example, direct evidence of variability in neural representations of material that has been tested (see author's brief, "Consolidation of learning") is restricted to a single fMRI study with adults. This evidence is aligned with current psychological theory based on numerous behavioral studies. However, further imaging research study involving, say, children learning curriculum, would help validate this concept.

These caveats have practical significance for emphasising that these are early days for a scientifically informed approach to teaching and learning and help indicate where future research might be focused in areas that would be very pertinent to education. However, they do not dismiss the central claim made here: *In teacher training and development, we now have sufficient knowledge to begin explaining and promoting core classroom learning practices using scientifically informed concepts of learning.*

			Principles of instruction (Rosenshine, 2010)										Principles for Emotion and Learning (Pekrun, 2014)									
			1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
			Daily review	Present new material in small steps	Ask questions	Provide models	Guide student practice	Check for student understanding	Obtain a high success rate	Provide scaffolds for difficult tasks	Independent practice	Weekly and monthly review	Understanding emotions	Individual and cultural differences	Positive emotions and learning	Negative emotions and learning	Self-confidence, task values and emotions	Emotion regulation	Classroom instruction and teacher emotions	Goal structures and achievement standards	Test-taking and feedback	Families, peers and school reform
Scientific concepts explaining underlying processes	ENGAGE	Individual differences in engagement							X				X	X	X	X	X	X		X		X
		Approach response			X				X				X		X		X		X	X	X	X
		Fearfulness and anxiety		X		X	X	X	X	X			X	X		X	X	X	X	X	X	X
		Understanding plasticity											X		X	X	X	X		X	X	X
	BUILD	Prior knowledge	X	X	X			X				X										
		Connection-making brain development	X	X	X	X	X			X												
		Multimodal/multisensory representation					X			X												
		Unconscious communication, MNS													X	X			X			X
	CONSOLIDATE	Practice, working memory, automatization	X	X	X			X		X	X	X										
		Variable representation of knowledge in brain	X		X			X			X	X										
		Sleep	X								X	X										

Table 2. Mapping of core scientific concepts to teaching principles as identified in Ref. [23,24]

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