Neuronal Structuring, Learning, and Instructional Technologies: Scaffolding Students along Abstract-Concrete Thinking

David Hung

Abstract

In this paper, we first present three axioms of learning from a neuronal structuring perspective, giving light to how neuronal structuring might lead to learning. From such a perspective we highlight the instructional approaches of constructivism and behaviourism congruent to the axioms. Subsequently, we argue that in essence, we need to scaffold students along the lines of both abstract-general and concrete-authentic thinking. Our argument is that both forms of thinking might foster neuronal structures which are stable and rich. We also discuss how teachers can use instructional technologies to scaffold students along the concrete-abstract continuum. From such a discussion, we hope to balance the views of educators who advocate strong views of either concrete or abstract methods in pedagogical approaches.

INTRODUCTION

As a theoretical grounding for this paper, we present three axioms or principles of how neurons in our brains structure themselves through learning experiences. The fundamental basis is that the richer the constructing process or experience, the more complex the neuronal structures which would evolve. The human brain is powerfully shaped by genetics, development, and experience (Edelman, 1989). It actively shapes the nature of our own experiences and of the culture in which we live. Stimulating experiences create complex reciprocal connections among neural structures. In essence, practice in the context of stimulating applications lead to more stable and rich neuronal structures.

In the process of explaining the concepts of how the human brain works in the subsequent sections, we have intentionally used quotation marks on certain words to metaphorically describe the links between external activity or experience and internal neuronal wirings (e.g., "schemata"). Because no scientific tools are currently available that can accurately monitor or trace the external links to the internal ones, the axioms discussed in this paper are theoretical (but sound) conjectures.
Current brain imaging techniques have advanced neuroscientists’ work but many of the findings are still subject to different interpretations. In the words of Steven Pinker, author of *How the Mind Works*, “Methods such as aphasiology and neuroimaging are a bit like using bomb craters and blurred satellite photos to understand the long-distance telephone networks” (Pinker, 1999).

**FIRST AXIOM — NEURONS THAT FIRE TOGETHER WIRE TOGETHER**

Let us start with the infant brain. From birth, many of the neuronal structures — which become stable over time — evolve to their current states through the child’s social interaction with others and with the world. With each new learning experience, neurons “learn” to fire together for a given activity or task. Whenever the child re-enacts a similar activity, relatively speaking, the same set of neurons get fired. With each new learning procedure added to a similar activity, more neurons are recruited to join the complex network, and structuring and re-structuring occurs for that experience. In essence, neurons that fire together wire together (Ratey, 2001). In other words, through application and experience, the brain strengthens the “wiring” (Bransford, Brown, & Cocking, 2000) of the neurons that pertain to a particular knowledge gain. Through use and application, the neurons involved take a particular form and structure. By not using the formed neuronal structure thus formed, the neurons pertaining to that structure may weaken and gradually break up or disintegrate.

Over an extended period of time, the child acquires a vast pool of knowledge gained through interactions with the world through manifold ways — reading, doing, listening, memorizing, etc. Our claim is that when the child engages in novel tasks through many similar opportunities and through manifold entry points — reading, memorizing, etc. — neurons are recruited afresh and the neuronal structures evolve and establish themselves with each experience. By recruiting neurons, the conjecture by neural scientists is that “unused” neurons (that were earlier structured) are reused for other fresh or novel purposes. Such a conjecture is based on the understanding of the biological nature of the human brain which is predominately structured for survival purposes (Edelman, 1989). The recruitment and restructuring of neurons are for optimal performances in memory retrievals and actions.

Alternatively, when knowledge is acquired in a surface or superficial way — perhaps through rote methods — the neuronal structures are not “rich” or densely interconnected. With more
interconnectedness in neurons, a better equivalent understanding (from the perspective of the learner) is attained. From multiple angles through which the knowledge is tested and acquired — doing, experimenting, trial and error, making mistakes, etc. — the more associations the neuronal structure makes through recruitment, the richer and more stable the network structure becomes. In this sense, practice makes perfect!

In other words, "what we reap is what we sow". With more time and energy spent on acquiring a certain knowledge, a corresponding strengthening of the neuronal structure is reached. Hence, "old habits die hard." Why? Because the neurons that fire together for that habit are so wired up! How then can habits be broken? Through engaging in unfamiliar activity (opposed to that habit), that is, by trying to form new neuronal structures unrelated to the old habits — neurons have to be recruited from elsewhere in the brain. This includes recruiting from neurons that were formerly wired up for those old habits. This leads us to a second axiom.

**SECOND AXIOM — USE IT OR LOSE IT**

Related to the quitting of old habits, we recognize the second axiom to be that neuronal structures which are not activated may lose its structural bonds — due to recruitment elsewhere. An example is as follows.

If students learn knowledge through surface learning mechanisms so that as they can represent the facts in examinations, but subsequently the knowledge is not used or applied, such knowledge would likely be inert. As the saying goes: "after the exams, all the knowledge is returned to the lecturers!" It is like retaining knowledge and facts in our short-term memory and subsequently downloading or off-loading them in the examinations. As the knowledge structured and stored in students’ brains is not used, applied, tested, etc., it soon disassembles (because of the earlier principle of neurons being recruited for other purposes; see Ratey, 2001) and it is as if the students had not learned it in the first place.

Imagine the number of hours spent unprofitably when we have lost all the knowledge seemingly cramped into our heads. Also, imagine the amount of time spent in learning particular sets of knowledge if we are not in any profession that requires the use of it. Such knowledge (fragile neuronal structures) would seem to be lost. Or if knowledge is not retrieved, it is as good as not having learnt or possessed it. On the
contrary, skills that we have picked up over time and through experience, for example, cycling and driving, are continually reinforced through practice and use in daily life. My sense is that because such skills have social connotations, in that they are common everyday observable phenomena, the re-learning for such activities and tasks are continuously reinforced.

It all goes to show that learning specific knowledge "just-in-time" has its merits. When we need to use calculus for certain applications, and when we learn it nearer the time we need it, the neuronal structures attained through that need would be richer and more stable. In other words, there is no need to rush students into learning knowledge earlier and still earlier — because it is just not efficient to teach students knowledge which they will not use in the near future. They will forget and we will have to re-teach them — expending unnecessary time and effort. Although the argument is that it is easier to re-learn a concept, knowledge, or task the second or third time around, my argument here is for a more optimal curriculum. Such a balance can only be possible based on a more accurate understanding of the intellectual and emotional standing of the students at any particular stage in their learning journey.

There are two issues to learning that are important in the above two axioms — rich and stable neuronal structures. Neuronal structures can be stable but not rich. For example, through repeated rote learning, certain knowledge concepts can be very stable — through continual reinforcement — but the concept is not necessarily rich with many associative neurons. A representative conceptual map might be represented as having minimal nodes. Take a concept like \( E=MC^2 \). Perhaps the student, through rote memorization, has established a "what is" node — just understanding what the form of the equation is and nothing else. Because he can recall the formula regularly, the formula’s "neuronal structure" is stable but may not be rich.

Yet another more mature physics student might understand the "who", "what", "where", "when", "why", and "how" of applying the formula in various problems related to the Einsteinian concept of relativity. He or she possesses a complex "neuronal structure" relating to the concept of \( E=MC^2 \). However, complexity may not necessarily be stable i.e. "hard-wired". The complex neuronal structure also becomes stable and rich through repeated use and application.

Of late, there have been debates on the superiority of constructivism (where students learn to construct meanings, for example, deriving formulae through first principles) over behaviourism (stimulus-
response and reinforcement). It would seem to suggest that when we want to establish stable neuronal structures of concepts, there is a need for continued practice and reinforcement — practice preferably through manifold and differing applications. Alternatively, when we want to establish a rich and complex neuronal structure (with regard to who, what, where, when, why, and how), constructivism seems to be more appropriate. Moreover, the constructivist approach also advocates more than one perspective or understanding of a particular view of knowledge. Thus, the constructive approach further enriches the “schemata” developed, adding to the richness of the understanding. A point to note is that constructivism is seen here as not just an instructional method but a fundamental stance in encouraging students to construct new knowledge and conceptual understandings. However, balancing the constructivist stance with the more traditional behaviourist stand, I would like to suggest that continued practice through various applications (seemingly behaviouristic), may yield similar results to constructivistic methods because the learner may pick up the who, what, where, when, why, and how through practice.

The bottom line is that learning (any concept, experience, etc.) has to be both rich and stable in terms of neuronal structures undergirding that learning. Whether we start with abstract concepts, for example, formulae or notions such as memorizing multiplication tables, these currently stable neuronal structures (assuming there is repeated rote learning involved) would not become "rich" unless there are many occasions for exposing the students to varied and concrete applications — we term this moving from abstract-general to concrete-authentic learning through applications.

Alternatively, we may start with concrete situational cases, problems, scenarios (like the current vein of problem-based learning, case-based reasoning, etc.) with our students. Students begin to establish rich and complex contextual understandings of concepts relating to the problems and scenarios presented. However, these concepts would be further strengthened if students are given opportunities to abstract principles and patterns across problems and scenarios. Through the applications of many problems and cases, students begin to form not only rich neuronal structures but also stable structures which have elements of similar patterns across situations (the “why” nodes in their concept maps). These patterns enable the students to understand “why” something happens the way it happens. We term such learning, moving students from concrete-authentic to abstract-general thinking through pattern recognition across applications.
Basically, teachers can move from abstract to concrete or from concrete to abstract in their instruction — but the fundamental idea is that for rich and stable neuronal structures there must be opportunities for students to practise on applications across both sides of the continuum. To this we add the third axiom. For good learning to happen, we need meaningful meaning.

**Axiom Three — Meaningful Learning Will Result in Rich and Stable Neuronal Structures**

To summarize the above discussion, we reiterate that richness in neuronal structures results from students being exposed to a variety of examples, applications, and situations with reference to certain domains of knowledge. Stableness in neuronal structures, however, springs from practice. Thus for meaningful learning, students need to practise and re-practise in the context of varied and concrete applications. Somehow, the context in which students engage in tasks have a profound impact on the way they remember the actions and events related to that particular task (Biggs & Telfer, 1987). In other words, remembering is a completely emergent, biological-psychological process of the brain. Recall and memory is intricately related to the activity, context, or situation in which that chemical or neuronal-memory change occurred.

**Abstract-Concrete Continuum**

In this section of the paper, I would want to shift gears and apply the above three axioms in the context of instruction and pedagogy. The fundamental question is: “How can we as teachers foster rich and stable neuronal structures in students' learning?” Through the “jungles” of discourse amidst academic debates between constructivism, behaviourism, didactic approaches, problem-based approaches, etc., there is a tendency to favour one approach over another rather than complement one with another. The key, in my opinion, is in moving students along the abstract-concrete continuum (see Figure 1 below).

Fundamentally, based on the above three axioms, rich and stable neuronal structures can only be attained through meaningful applications. Through such a process, students develop a “schemata” of neuronal structures with an understanding of the principles involved — constructed or derived abstract principles (from the Piagetian schemata perspective). Note that the abstract knowledge need not be memorized principles but could be constructed through application and
use. By "concrete" here we mean applications that approximate real-world situations.

![Abstract-Concrete Continuum](image)

**Figure 1.** Abstract-Concrete Continuum

From Figure 1, we see two kinds of processes — abstraction and contextualization. By abstraction, we mean the process through which learners derive principles from patterns of observable phenomena in the context of being engaged in concrete or authentic real-world problems or cases. Current pedagogical methods such as case-base reasoning, problem-based learning begin with concrete examples and scaffold students towards transferring patterns across situations (Hung, in press).

The other process is contextualization. By contextualization, learners or students are perhaps first taught rules and principles in an abstract form. Through application of these principles, learners begin to contextualize these principles, gaining knowledge of the relational meanings undergirding the principle. Such an abstract principle learning approach has been fundamental since the advent of schooling. Our belief is that schools should be engaged in contextualization, but unfortunately because much content knowledge has to be imparted, students lack time and opportunity to apply abstract knowledge in manifold ways. As a result, neuronal structures may be stable due to the drilling of abstract knowledge; however, rich and stable neuronal structures may be lacking.

There are currently debates advocating concrete to abstract approaches — for example the stand adopted by situated cognitivists (Brown, Collins, & Duguid, 1989; Bredo, 1994). Because knowledge and meaning making is always contextual in nature, learning should begin from concrete situations. The main argument of situativity when applied to school and learning contexts is that if the learning occurs exclusively in school-based or classroom-type situations there will
continue to be a gap between school and the real-world. Hence, learning theorists advocate authentic tasks—tasks that simulate the real world.

In general, situated learning environments are considered authentic when there is a similarity between what happens in school learning activities and some meaningful real-world context. However, one point to note is that no matter how authentic a task may be in the school context, it is not the "real thing"—but rather an approximation to the "real thing". The learning context is always conditioned by the constraints in the school where certain variables are controlled.

For example, since students are limited by the logistical constraints of going out on a river trip (which may not always be feasible), schools adopt approaches such as the Jasper video-based "authentic" tasks (Cognition and Technology Group at Vanderbilt, 1993). One may argue that the scenarios presented in Jasper may not be personally authentic. However, the video captures the variables of the experience. Controlled variables in this instance could be the time spent on the trip—the video capture could save the students' time in going on a field trip. One may take situated cognition to an extreme and argue that if students do not experience the urgency of the time variable (e.g., getting back home before the sun sets), they may not be able to experience the authenticity of the problem or project. Hence, in essence, authenticity when applied to schools is always an approximation of the real experience and not the real thing. So, in essence, we cannot claim school-based learning to be truly "authentic", but rather we are speaking of degrees of authenticity. Although authentic applications are usually concrete or real-life, we are advocating concrete (in our discussion) as encompassing the elements of authenticity.

Learning abstract- or principle-oriented knowledge is strongly opposed by situated theorists who perhaps do not realise that these activities are but "scenarios" with more controlled variables—that is, more towards the abstract or generalized end of the Abstract-Concrete continuum (see Figure 1).

On the other hand, learning that is increasingly abstract and less similar to real-world practice is considered to be more "abstractable" or generalizable, precisely because it is not tied to any specific instance. In other words, it is reckoned that generalizable learning must occur "out of context" if it is to be applied to multiple situations, and that only out-of-context learning can lead to abstraction, generalization, transferable knowledge, and cognitive efficacy in future life situations (Brown, Collins, & Duguid, 1989). The drawback of this school of thought is that students often lack understanding of the contextual (rich schemata) underpinnings of such generalizable knowledge, so much so
that without seeing or perceiving the meanings surrounding the abstracted knowledge, they often misapply the knowledge.

To reiterate, we hope to create awareness of the point that the argument of concrete and abstract thinking from an instructional point of view should not be perceived in terms of the superiority of one to the other. Instead, one ought to recognize that the function of schooling is to develop the thinking processes of (scientific) inquiry with the intention of learning to transfer knowledge to generic situations and apply knowledge from principles to real-life scenarios (Bereiter, 1997). Hence, it is important to recognize that for meaningful learning—rich and stable neuronal structures—to occur, whether instruction occurs from authentic tasks or more generalized knowledge, the objective is always to provide students with experiences across the spectrum of concrete and abstract thinking.

If abstract knowledge is used as a starting point to instruction—that is with more controlled variables—then it is important for the teacher to ensure that what is learned is applied or transferred to as many other contextual situations as possible. On the other hand, if authentic situations are deemed a better starting point, then, the teacher should gradually decrease the number of contextual variables to allow for abstraction and consequent transfer of knowledge. Hence, as teachers, we need to know where the starting point is—whether the concrete or abstract end of the continuum or anywhere in between. We suggest that depending on learners’ ability and the kind of knowledge, the teacher could decide where he/she should start.

One possibly interesting example of starting from the more abstract end of the continuum is the learning of the Euler theory on prime numbers. For many decades, Euler’s theory in mathematics was taught predominantly in an abstracted manner—that is non-authentic—because there was no application of the theory until recently. Euler’s number theory was invented more than 200 years ago and only in recent times has the application of such a theory been useful to “cryptosystems” or systems requiring encryption. In other words, a university professor (before the advent of cryptosystems) had no choice but to start from the abstract-generalizibility end of the continuum when teaching Euler’s theory and consequently attempt to find application (if any) of the principles and concepts involved. The fact that this theorem still existed then (before cryptosystems) was probably because people who were mature in the mathematical community saw potential application with Euler’s theory. Thus, it is probably naive to claim that all learning should begin with authentic tasks as advocated by situativists.
TWO TYPES OF SCAFFOLDING

I have thus far presented the axioms to learning from the neuronal perspective and further discussed how these axioms can be actualized in instructional contexts. My argument here is that if we move students along both sides of the concrete (including authentic) -abstract continuum, students would inevitable attain understandings that have rich and stable neuronal structures.

The above discussion seems to suggest that if the starting point of the instruction is the concrete side of the continuum, the scaffolding would move towards higher abstraction or generalizibility. On the other hand, if the starting point of the instruction is more towards the abstract side of the continuum, the scaffolding should move towards the concrete or application end. Such a two-prong scaffolding process provides students with learning experiences which span the spectrum of both concrete and abstract meanings. Thus students are empowered to abstract situated knowledge and transfer it across contexts, and alternatively to contextualize abstract principles and apply them to real-life problems.

SCAFFOLDING FROM ABSTRACT TO CONCRETE THINKING

Abstract principles are generally simplified representations of the real-world where contextual variables have been controlled. In order to scaffold students to real-world authentic tasks, systematic staging — increase of complexity or removal of controlled variables — is needed.

In a computer-based simulation, concreteness (including the degree to which the simulation approximates authenticity) could be defined by the number of controllable variables. By controllable variables we refer to those crucial factors within a simulation program which the learner can manipulate. For example, in Sim City (a simulation-based instructional technology environment) learners can manipulate different types of buildings and facilities, frequencies of natural disasters, etc. The number of controllable variables would largely dictate the degree of concreteness of the simulation application. In the real-world, almost all factors can vary and thus these factors have a bearing towards the outcomes and consequences. By keeping some of the variables constant in a simulation application, we are decreasing the complexity, concreteness, or authenticity of the system.

Learning could be facilitated towards concreteness through learning environments and simulations if the applications provide a sufficient number of controllable variables and a scaffolding process
where the control of the variables would be systematically reduced in order to increase the complexity or concreteness (see Figure 2).

![Diagram showing the relationship between decreased controlled variables and increased concreteness.]

**Figure 2.** Increased concreteness leads to decreased controlled variables

**SCAFFOLDING FROM CONCRETE TO ABSTRACT THINKING**

Alternatively, if we are to move from concrete to generic principles, learners need the disposition and skill to observe similarities across different concrete (as real-world as possible) situations. Students need to a) see similarities across contexts, trends which lead to something or some concept, and b) distinguish more relevant from less relevant information (Hung, 2000). Here, mind-cognitive tools such as concept maps, epistemic structures and outliners, spreadsheets, etc. are particularly useful. Today’s instructional technologies support concept-mapping (such as idea processors), visualization of data (such as Climate Watcher), simulations (such as micro-worlds supporting physics, mathematics, etc.) (Jonassen, Peck, & Wilson, 1999). Mind-tools can also be collaborative in nature, for example, we have communal knowledge bases such as Knowledge Forum which is a second generation of CSILE — a social constructivist knowledge building environment from the University of Toronto (see Learning in Motion website). Another example is CoVis (with a Collaboratory Notebook interface) by Northwestern University (see Oliver, 2000).

In addition, students also need to test their abstractions, make conjectures, and possibly assess the pre-conditions or assumptions which they hold. Simulations which allow students to test their preliminary hypotheses based on their abstracted principles, would be useful. In the context of these skills and functions which students need to engage in, tools which present sufficient authentic cases, stories, etc. such that students can abstract patterns would be useful. Increasingly, with the advent of e-learning, we are also witnessing the use of social-constructive tools, for example, knowledge forums, which also allow students to construct and test hypotheses and personal theories with one another.
Moreover, tools should assist human cognition in taking care of the possibly "lower level" computations and allow students to concentrate on pattern recognition. Technology can also assist in modelling or visualization, thus allowing humans to visualize trends. These tools can assist in searching, enabling the learner to engage in categorizations or any other higher-order thinking.

**Conclusion**

Finally, the point that we have made in this paper is that learning should result in stable and rich neuronal structures. Rich and stable neuronal structures spring from meaningful learning. For stable wiring of neuronal structures, we conjectured in this paper that through sustained practice, neurons that fire together would be wired together. Moreover, we also described how neurons that are wired up need to be constantly reactivated or used in applications, otherwise newly formed neuronal structures may recruit neurons from inactive ones.

From an instructional perspective, meaningful learning can be facilitated through moving or scaffolding students along the concrete-abstract continuum. Exposing students to the varied situations and principles of any particular concept requires that students practice the applications of concepts across manifold problems, cases, situations, etc. As a result, students would acquire useful productive knowledge, maximizing their time spent in learning. It is hoped that this paper has in some ways clarified the distinctions between various pedagogical approaches such as problem-based learning, where starting points of instruction are at the concrete end, and didactic approaches, where abstract knowledge is advocated. The issue for us is not really the debate on the starting points of instruction, but rather the exposure to both sides of the concrete-abstract continuum.

*Dr. David Hung is an Assistant Professor with the Instructional Science Academic Group at the National Institute of Education, Nanyang Technological University. His research interests are in learning both at the social-cultural and individual levels of cognition. In addition, Dr. Hung is involved in Educational Technology R&D work, and he writes regularly as a contributing editor of “Educational Technology”.*
REFERENCES


Learning in Motion website: http://www.learn.motion.com

