Constructivism, Direct Instruction and the Free-energy Optimization Principle: Cognitive Perspectives on Learning

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Abstract

Constructivist instruction favours learning strategies that emphasize student independence (Bodner, 1986; Murphy, 1997). It suggests that limiting direct guidance and increasing constructed thinking through a student-centered approach will maximize higher order learning outcomes including creativity and originality (Liu & Matthews, 2005). In contrast, direct instruction models propose that in light of limited working memory capacity, increased guidance and feedback produces better learning outcomes (Sweller, 1998). Direct instructivists suggest that explicit guided instruction is crucial to develop skill acquisition and ad hoc information attainment (Kirschner, Sweller, & Clark, 2006). Friston's (2005) introduction to *learning as optimization* [free-energy] perspective enables a new non-antagonistic outlook that illustrates the importance of both constructivist and direct instructivist educational philosophies in routine brain functioning. In this paper I argue that this assimilative approach suggests new opportunities to investigate questions surrounding accuracy, creativity, and learning.

Introduction to Established Pedagogy

Understanding Constructivism and Instructivism

Constructivism is a student-centered learning theory and/or paradigm (Liu & Matthews, 2005). In constructivism, the learner is encouraged to be the primary producer and director of his/her own education, while the educator ideally plays a facilitating role. Developing the learner's independence in his/her process to become better versed with the chosen subject is emphasized. Within the constructivist philosophy, higher order outcomes such as creativity and innovation are strongly valued, and are said to be primarily constructed qualities (Husen & Postlewaite, 1989; Kintsch, 2009). Indeed, knowledge for the most part within constructivist accounts is largely seen as being constructed. Recognition of each learner's individuality is acknowledged as being important, and as such, past experience is thought to have a significant effect on learned outcomes (Bodner, 1986; Husen & Postlewaite, 1989; Kintsch, 2009; Murphy, 1997). While it can be argued that this description presents a very vague account of constructivist pedagogy, it nonetheless presents a broad outline that aligns with the existing educational literature. Cognitively speaking, with such an inner-focused, experience-dependent, learner-centered perspective, constructivism can be seen as a particularly active form of learning for learners.

In contrast, instructivist philosophy emphasizes an explicit form of instruction (Sweller, 1988). Instructivism focuses on skill acquisition and information recall through student dependent methods (i.e. lectures and demonstrations), and is designed in light of the seeming constraints of students' working memory (Cooper & Sweller, 1987; Klahr & Nigam, 2004; Tuovinen & Sweller, 1999). At the center of this learning process is both the learner and the educator, who it might be said, now share the roles of producer and director. As the educator becomes a more focal figure in the learning exercise, he/she is simultaneously charged with an increased responsibility to disseminate selected information as well as an increased responsibility to provide prompt and appropriate feedback (Klahr & Nigam, 2004). Perhaps in

light of the somewhat diminished roles and responsibilities of the learner, the instructivist methods by comparison to the constructivist, can be viewed as looking to find a cognitively less demanding approach.

Although, as Clark (2009) notes, "all of the participants in the debate (between the constructivist and instructivist paradigms) seem to agree about many of the forms of instructional support that must be offered to most students in most educational environments," (p. 158) there still remains many disagreements between constructivists and direct instructivists on the course of best practice. Despite their differences, constructivism and direct instruction paradigms agree on a number of issues, including: teacher effectiveness, the need for providing student-centered support, promoting authentic and relevant problems, applied-based outcome measures, and the gradual reduction in scaffolding as learning gains are made. In this, the number of ways in which constructivism and direct instruction paradigms seem to agree may be greater than the ways in which they do not. Yet the fracture between the two camps preserves the major divide within education research and theory (Clark, 2009).

According to Clark (2009), the main source of disagreement between the constructivists and instructivists is the degree to which learner guidance needs to be offered. The understanding of the particulars about *when, how much, what type,* and *to whom* guidance must be provided is at the heart of much of these debates (Clark, 2009). Generally, discussions have moved away from questions of *what can work* to questions of *what will work best for learners*. Furthermore, at the center of many of the misunderstandings are the philosophical questions concerning ontological and epistemological stances on: monism, dualism, parallelism, objectivism, subjectivism, relativism, among others (Liu & Matthews, 2005). It is with such a concerted perspective that I hope to outline an approach in exploring the question of '*what does it mean to learn?'.* By borrowing both constructivist and direct instructivist tenets in conjunction with the Free-energy principle on learning as cognitive optimization, I explore the question, '*what will work best?'*

Dualism and Monism: Exploring Mind and Nature

Cartesian dualism refers to a particular philosophy of the mind. It describes a separation between the ideas of the non-material mind and material brain, between thought and substance, and between mental/cognitive phenomena and neurophysiology (Sperry, 1980). In short, this form of dualism promotes the idea that mental phenomena are non-physical. In contrast, monism does not adopt a separation between the mind and brain, but instead describes a physical connection between mind and nature, thought and action (Bracken & Thomas, 2002; Sperry, 1980). It is the monist perspective in combination with educational and neuroscientific ideas that reflect a Vygotskian educational philosophy on the connection and interaction of human rationality and the external world - the connection between *form* and *concept*. This assimilative perspective implies that there is a strong connection within neurophysiology, cognition, and behavior. In this, I suggest that the *form* of brain pathways and processes interact closely with *concepts* of 'how we learn' (Crick & Koch, 2005; Friston, 2005). This perspective questions the notion of dualism and brings the worlds of education and neuroscience together. The core idea asserts that there is a necessary linkage between human physiology, human cognition, and human environments.

According to Cobb, Vygotsky argued that "knowing is relative to the situations in which knowers find themselves" (Cobb, 1996, p. 339). This line of reasoning emphasizes the learner's constant need to restructure their cognitive system to meet the needs of their changing environment by integrating new information. Furthermore, Vygotskian theory implies that the purpose of education is about more than the development of intellect and rationality (Liu & Matthews, 2005). However, according to Liu and Matthews, a dualistic paradigm at the heart of constructivism, behaviourism, and perhaps direct instruction, stands in the way of identifying relevant questions and solutions to current pedagogical problems. In this, the challenge to understand *learning* lies outside of the dualistic philosophy of the separation between the mind and environment. While I recognize that the distinction between "the human inventor vs. nature the creator"; as is a defining standard of constructivist theorist according to Liu and Matthews, I do not believe that this is a return to a mind and world parallelism, which is inherent within dualism (Liu & Matthews, 2005). Knowledge seems to be both constructed and conveyed, and its

construction is bound by the outer environment. If knowledge were to be fully constructed without concern to environmental realities, then the chances of the knower adapting to survive in the environment would be low. If knowledge is wholly conveyed, then there would be no space for creativity, interpretation and general subjectivity. In this sense, the relationship between the mind and the environment operates within a single domain where the mind and the environment are distinct rather than separate, and correlated but not parallel. It is my understanding that this perspective does not advocate for either dualism or parallelism. Buckminster Fuller (1968) articulates this argument effectively as he notes that:

> Our brains deal exclusively with special-case experiences. Only our minds are able to discover the generalized principles operating without exception in each and every special-experience case which if detected and mastered will give knowledgeable advantage in all instances." (p. 1)

Therefore, the either/or discourse present in the monism/dualism divide does not seem to fit the particular evidence that has been provided in my argument.

The Free-energy Optimization Principle

Describing the Free-Energy Optimization Principle

The Free-energy Optimization principle is built on the ideas of the Bayesian brain hypothesis (Huang, 2008). The Bayesian brain hypothesis supposes that the brain is akin to a probability inferencing (generative) machine (Friston, 2010), which is a machine that uses statistical probability estimates to infer and encode its representations of the world. The general function of this organic machine, according to the hypothesis, is in making and updating predictions of the outside world within which it struggles to exist (Griffiths & Tenenbaum, 2006). The updating of predictions is referred to as *optimization*. This assumption establishes the essential modus operandi of the brain, which leads to the important question, '*how does this work?'*

According to Friston (2010), there are two general methods employed in cognitive processing. The first method can be described as internally generated predictions, heuristics or schemas, which are based on experience that have already been acquired and integrated into the brain's own collection. This generative process can be viewed as being 'top-down' (Friston, 2005), where predictions that come from the highest functions of brain operations produce responses and behaviours at the lower end of the process. These processes are a product of the learner's own previously acquired and assimilated knowledge and experiences. From the highest systems of brain functioning down and out through the body towards the environment, this process is 'top-down' in direction. This, it should be said, is an overgeneralized description of 'top-down processing'; however, it provides a straightforward and understandable overview.

According to Friston's Free-energy principle, the second method used by the brain to make and update its representations is based on newly acquired information entering the system – a 'bottom-up' directed process (Friston, 2005). New information can be acquired in the form of sensory perceptual routes. It can be visual information about an object's location and auditory information about a particular conversation. Information enters from the lower levels of sensory recognition and stimuli detection, and moves upwards towards being integrated within the brain's collection of already learned experiences (Friston, 2005).

Paradigm Philosophy

Free-energy, Constructivism, Direction Instruction, and Philosophy

At this point, I intend to reemphasize a link between education and neuroscience philosophies on learning. I suggest an overlapping, though perhaps not complete, similarity in the relationships between the 'top-down vs. bottom up neuroscientific explanations' with that of 'constructivism vs. direct

instruction educational approaches' respectively. It seems possible that the top-down learning pathways described in Friston's (2005) neuroscientific hypothesis relate closely with the experience-dependent constructivist pedagogical methods as is described in education research. Likewise, it seems possible that the bottom-up pathways described within neuroscience relate strongly with stimulus-dependent direct instruction approaches. While I do not suggest a complete overlap, I am intrigued by the potential to explore the ways in which such a '*Free-energy, Constructivism, Direction Instruction*' connection could lead to future research, which I intend to describe briefly in the next sections.

Prediction Error

The major impediment in the way of inferential systems is error, specifically prediction error. In assuming that the external environment provides the limits within which the mind can successfully operate, the Free-energy concept of error prediction can be thought of as the difference between what the knower knows and how the environment actually exists. The main goal of the brain is essentially in minimizing this prediction error and achieving adaptive understandings of the actual world. However, the Free-energy principle discusses accuracy as opposed to adaptive understanding as the main aim of the brain. According to Free-energy principles, if the prediction made by the brain is accurate, then there should be little or no difference between its predictions and the actualities of the external environment in which it is a part. Therefore the difference between the predictions made by the brain and what is actually existing or is actually sensed is known as: free-energy or useless energy or entropy or surprise or *prediction* error (Friston, 2005).

Through the updating and maintenance of its predictive cognition (Friston, 2010) using both top-down and bottom-up assimilative processes where experience changes in response to new information, accuracy and/or adaptive understanding are achieved. For example, as Huang (2008) describes, when we listen to someone talking, our brains are not simply receiving bottom-up auditory information, rather our brains are also predicting what it expects to hear and constantly revises its predictions based on what information comes next. In such a way, these predictions strongly influence what is actually heard, even allowing the listener to make sense of distorted or partially obscured speech. It is this continuously converging feedback relationship between top-down and bottom-up approaches that facilitates learning within the brain. In this, both constructivist and direct instruction approaches are at work in the brain, each performing a different but simultaneously effective function in a continuously operating learning process.

Research Implications

Exploring the Need for Further Inquiry

In integrating constructivism, direct instruction and the free-energy principle, we are afforded new space to think about learning. Buckminster Fuller (1979) expressed children's ability to imagine and test, to predict and experience, to explore and sense, and to be simultaneously top-down and bottom-up:

> Children are born true scientists. They spontaneously experiment and experience and reexperience again. They select, combine, and test, seeking to find order in their experiences - which is the mostest? which is the leastest? They smell, taste, bite, and touch-test for hardness, softness, springiness, roughness, smoothness, coldness, warmness: the heft, shake, punch, squeeze, push, crush, rub, and try to pull things apart. (p.1)

In light of this constructivist-instructivist-free-energy assimilative approach, we can imagine a developmental progression where the importance of the top-down (i.e. constructivist) and bottom-up (i.e. direct instruction) learning processes change over time as we mature and gain expertise (Kalyuga, Ayres, Chandler & Sweller, 2003). How can the inclusion of this monistic neuro-cognitive slant offer another insight into the study of human learning? Essentially, the neuro-cognitive approach attempts to identify specific operational brain functions that could be tied into educational-cognitive explanations. If we were

to investigate changes to the way individuals learn as they develop—either as a function of age or education—by linking the effects of educational approaches (i.e. constructivism or direct instruction) with the specific brain pathways, we could offer a more comprehensive understanding of what happens to learners as they learn.

Linking Pedagogy and Brain Functioning

If we were to investigate changes in learning style over time, it would also be necessary to confirm a link between top-down pathways and constructivist instruction – and/or bottom-up with direct instructivist methods. Observing actual brain activity associated with constructivist-instructed learners in contrast with those who had been instructed through direct instruction could offer important insight into the effects of educational approaches on the brain. Observing brain activity would also allow for an assessment of the significant differences in the way the brain operates in accordance with the different pedagogical approaches and deferring learner characteristics.

Changes in Learning Styles

As with the rapid changes in early infancy (Fox & Rutter, 2010), as we mature, there may be a shift in our preference or dependency in using the top-down, internally generated predictive processes versus bottom-up external methods. As an exploratory hypothesis, an individual gradually reduces dependency on bottom-up learning as they generate a dependable internal predictive system, which happens as they mature. This shift implies there would be significant differences in the way novice and expert individuals perform as a result of being taught through bottom-up versus top-down means (Kalyuga et al., 2003). With the inclusion of age and experience varying participant groups, it would be possible to investigate the changes to the way different forms of information are learned. Perhaps this variation in age/developmental stage across learning situations explains why variation in applying constructivism is perceived as necessary for learners (Clark, 2009; Kalyuga et al., 2003; Klahr & Nigam, 2004). There may be periods when constructivist philosophies are better methods of achieving learned outcomes. Divided into equal groups of constructivist pedagogy and direct instructivist pedagogy, further subdivided into groupings for age, controlling for developmental stages and sorting for level of expertise –we may be able to measure the effects of constructivist and direct instructivist education approaches against such dependent demographic-educational variables. My suggestion is that this work would shed important light on these questions and hypotheses.

Exploring Accuracy and Adaptiveness

Another significant question to consider is whether the main goal of the brain is to reduce error (accuracy) or to increase adaptiveness (creativity). It is interesting to note that constructivism promotes the value of 'creativity,' while direct instruction emphasizes the importance of 'accurate' recall. The distinction between accuracy and creativity is an important point that could help shed further insight on subjectivity and interpretation in learning processes. If the ultimate goal in learning is to reduce error and free-energy, then it might seem counterproductive to want to expend energy by nurturing creativity. On the other hand, perhaps the truly creative individual is able to foresee multiple highly probable and/or highly obscured outcomes – thus serving to effectively narrow down probability sets. Exploring the relationship between accuracy and achieving adaptive interpretation within the mind of the learner; analogous to that of the relationship between fitness and diversity within evolutionary biology (Livat, Papadimitriou, Dushoff & Feldman, 2008), could lead to a number of other interesting follow-up questions and insights. It might lead us to an objective definition of what is meant by 'creativity'; a definition that would be highly associated with the idea of accuracy (prediction error). Accuracy is emphasized in equations and calculations, which remind us of how pointedly focused we sometimes are at arriving at an exact answer. However, creative solutions are often appreciated as they can help to direct us to questions and solutions not yet considered. Even still, creativity can and should be appreciated on its own merit. Do we appreciate creativity as its own virtue, or as a means to a specific end? Are processes of solving and adapting (creativity) in themselves as important to us as the end outcome of accuracy (low prediction error)? If so, how can we nurture the development of these cognitive processes? These questions are worth considering in a future paper.

Concluding Discussion

In assuming that our minds operate continuously and simultaneously through two semi-distinct cognitive processing strategies (Friston, 2010): the inner inferential (top-down constructivist) pathways strategy and the outwardly-sensing (bottom-up direct instruction) perceptual pathways strategy, I am better able to approach the questions as to why there has been a persistent divide within educational philosophy - between constructivism and direct instruction proponents, and between the dualist and the monist. When considering such questions, I find it useful to remember that based on human neurocognitive functioning there appears to have been empirical reasons that support the use of both forms of learning and teaching (Friston, 2005). Consequently, it becomes unproductive to continue asking the question of whether direct instruction is best at the expense of constructivist philosophy, or vice versa. These are false binaries that are unsupported by the cognitive processes I have described throughout this paper. It is curious that while the seeming incompatibility between the constructivists and instructivists seem to result in a significant educational divide, within the learning brain the same competing strategy appears to result in more successful outcomes - becoming essentially a complementary feedback system comprising the larger functioning of *learning as optimization.*

In light of this integrative stance, the importance of trying to unravel particulars of: *when*, *why*, *how*, *how much*, *what type*, *for whom*, and *for what reasons do we learn?* becomes that much more essential. With the introduction of this new outlook I am afforded an opportunity to leverage the tested insights of both constructivism and direct instruction with that of a flexible and potent neurocognitive framework.
It is my opinion that this integrative stance; which spans across theoretical divides and disciplinary boundaries, can allow researchers, educators and perhaps even the learners themselves, for new perspectives, new questions, new descriptions, as well as new investigative directions.

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