A Framework for Organizing and Translating Science of Learning Research

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Introduction

The term ‘Science of Learning’ (SoL) encompasses a broad range of scientific disciplines; from basic neuroscience to cognitive psychology to computer science to social theory. Despite this wide array of interests, however, the goal of many SoL programs is the same: to determine and develop methods that teachers and students can use to improve the learning experience.

As with any multidisciplinary endeavor with the ultimate aim of “application”, an important consideration concerns how the knowledge obtained from disparate research programs fits together to form a coherent and useful whole (Glasgow, Lichtenstein, & Marcus, 2003). As can be inferred, trying to determine how data obtained at micro-scales links to data obtained at macro-scales is not a trivial task - furthermore, it’s far from clear if these types of links are meaningful or in any way beneficial for the larger goals of classroom education (Bruer, 1997). For instance, what support is there to suggest knowledge of calcium driven potentiation at the neural synapse can influence a typical teacher trying to help a student differentiate between the numerator and denominator in a fraction?

In order to ensure research findings are correctly applied and educators are presented with only the most solid ideas, a coherent and structured framework through which relevant information can be localized, interpreted, understood, and built is required. It is a long way from the neuron to the neighborhood (Shonkoff & Phillips, 2000); more specifically, there is a tremendous gap between biochemical processes which occur in isolated regions of the brain and the socio-cultural interactions which aid students in becoming good, educated citizens. What is needed is a clear pathway from the former to the latter that takes into account the contexts in which teachers apply their practice. This pathway is what we hope to build here.

Different Types of Translation
The primary aim of many SoL programs is successful translation. In the applied sciences, translation typically refers to the process of interpreting information and/or ideas devised during ‘research’ into a form that relevant consumers can understand and utilize. The most obvious example of this translation process at work is in healthcare. Clear mechanisms are in place to translate findings from the basic sciences of chemistry, biology and physics into meaningful processes and procedures that can be readily implemented by medical practitioners (Sussman et al., 2006). With regards to SoL, this translation process similarly means adapting outcomes elucidated in the laboratory into a form that practicing teachers and students can easily grasp and apply to their own practices (however, there is a large and important difference between medical and educational translation: this will be further explored later in this chapter).

Although it is often spoken of in singular terms, translation can be divided into at least three unique types.

The first type of translation is termed prescriptive. Prescriptive translation aims to specify activities and/or behaviors that teachers and students can undertake to best ensure specific learning outcomes - essentially, addressing the question “what should I do?” For instance, the concept of the priming (whereby the presentation of specific information or activities prior to a lesson which serve to scaffold how later material is interpreted and understood) has been well elucidated in SoL research and several specific, prescriptive strategies are emerging that can be incorporated into daily teaching and learning practices (Wilde, Koegel, & Koegel, 1992).

The second type of translation is termed conceptual. Conceptual translation allows for teachers and students to understand educational phenomena through the lens of varied scientific theories - essentially, addressing the question “why does this work?” It’s important to note that this type of translation does not offer advice on what unique practices individuals should undertake; it merely contextualizes and offers a theoretical explanation for why said practices are (or are not) effective. For instance, although some educators may be inspired by the concept of neural adaptation and use that framework to justify the success or failure of specific activities, this interpretation does not impact the content, structure, or outcome of the activity itself (Walsh & Anderson, 2012).

The third type of translation is termed functional. Functional translation allows for direct alterations of physiology to expand or restrict the number and type of educationally relevant practices an educator or learner can successfully undertake. Again, it’s important to note that this type of translation does not speak to what practices an educator or learner should undertake. For instance, if a learner were to suffer damage to the auditory cortices leading to deafness, then all future learning activities would necessarily need to utilize visual or other sensory modalities. Of importance here: damage to the auditory cortices does not instruct the teacher or learner as to which non-auditory activities to undertake, how to best undertake them, or how to measure their impact.
As the distinction between prescriptive and functional translation may be somewhat unclear, it might be worth further clarifying using a specific example. Some students who suffer from disorders of attention (e.g., ADD/ADHD) turn to pharmaceuticals in order to alleviate symptoms which, in turn, can lead to improved educational performance (Loe & Feldman, 2007). At first glance, the ingestion of drugs may appear to be prescriptive; however, a closer examination reveals that, although taking a pill may allow for an individual to better interact with learning activities, this does not engender learning itself. Pharmaceuticals do not inform an individual as to which activities to undertake, how to structure them, or how to measure them in order to learn language, math, or geography. Accordingly, pharmaceuticals represent functional translation rather than a prescriptive translation.

As can be inferred, the most demanded form of translation from SoL research is prescriptive (Pickering & Howard-Jones, 2007; Hook & Farah, 2013). Although conceptual and functional translations are no doubt important, they are already extant in some form within many classrooms around the world. With regards to conceptual translation, educators and learners at all levels utilize ideas from many different SoL fields—such as neuroscience (plasticity: Ansari, 2012), biology (evolutionary theory: Geary, 2008), and computer science (information coding: Pressley, Borkowski, & Schneider, 1989)—to explain why certain practices do or do not work, even though these concepts do nothing to instruct an individual how to specifically structure, perform, or measure said practices. Similarly, with regards to functional translation, educators and students at all levels are utilizing interventions—such as drugs (Ritalin: McCabe et al., 2005), drinks (RedBull: Malinauskas et al., 2007), and therapies (Deep Breathing: Birkel & Edgren, 2000)—to directly modulate brain/body function in order to enhance educationally related behavioral/cognitive performance, even though these interventions do nothing to indicate which behaviors/cognitions to undertake in order to engender learning.

With this chapter, we will be exclusively considering the issue of prescriptive translation.

Characteristics of Prescriptive Translation

Attempts at prescriptive translation cannot aim to provide precise formulae that guarantees all students will achieve intended learning outcomes in varied contexts. Without taking the nuances of the educational setting into account, it can be deceptively simple to conjure up highly specific teaching and learning approaches that seem valid based on work in the laboratory, but suffer from a lack of generalizability. Any translation approach aiming to provide prescriptions for teachers to implement in their classes must, therefore, be mindful of the context in which teachers find themselves rather than use the rigor of laboratory research to give the illusion that there is a one size fits all solution to a pedagogical issue.
Unfortunately, the desire and pressure to generate highly-specific *prescriptive* translation of SoL research has led many to prematurely champion ideas which ultimately prove useless in the classrooms. In fact, most concepts people would refer to as educational- or neuro-myths (e.g. ‘individuals have unique and specific learning styles’ – see: Lodge, Hansen & Cottrell, *in press*) represent ideas that were born in a laboratory and were rushed to prescriptive application without proper and effective translation.

Ideal SoL prescriptive translation serves to provide evidence-based advice to teachers that allows them to make informed decisions about what will work for them and for their students in the unique contexts in which they find themselves. For this reason, rather than being overly dictatorial, effective prescriptive translation will necessarily remain moot on the point of specific implementation within specific contexts. Rather, the final stages of applicability (*where the rubber meets the road*, so to speak) and iteration will always remain fluid and require the input, ideas, and professional judgement of individual teachers within individual settings.

This all serves to highlight the importance of developing a robust translation framework by which laboratory results can be explored further and prescriptive classroom applicability established in a meaningful fashion. This type of framework would be important not only to researchers (as it can guide researchers in the move towards applicability) but also to educators (as it can clarify what teachers can meaningfully expect from the laboratory).

**Levels-of-Organization, Emergence, and Incommensurability**

In order to understand the framework developed, there are several scientific and philosophical concepts that must first be elucidated.

The first important concept to understand is *levels-of-organization*. Within a living system (e.g. humans), the most common definitions of *levels-of-organization* are compositional (Oppenheim & Putnam, 1958; Wimsatt, 1994; Kim, 1999). More specifically, each ‘level’ that constitutes a living system is composed of the material extant in the preceding levels. For instance, within biology, levels-of-organization typically progress accordingly:

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\text{Cellular} \rightarrow \text{Tissue} \rightarrow \text{Organ} \rightarrow \text{Organ Complex} \rightarrow \text{Organism} \rightarrow \text{Population}
\]

In this instance, *tissues* are composed of *cells*; *organs* are composed of *tissues*; etc. It is commonly held that as compositional levels increase (from cell to tissue to organ, etc.), so too does complexity (in this case, complexity is simply defined as any increase in the quantity of individual parts that interact to form a ‘whole’: for review: Lewin, 2000). For instance, a *tissue* is composed of many different collaborative *cells*, thereby making a tissue more ‘complex’ than a single cell. Similarly, *Organs* are composed of several varied yet interacting *tissues* which, in
turn, are composed of a many of different collaborative cells, thereby making an organ more complex than an isolated tissue or single cell.

The next concept to undergird our framework is emergence: a process whereby novel and coherent structures, patterns, and/or properties arise at ascending levels that are neither exhibited within nor predictable by preceding levels (for discussion: Bedau & Humphreys, 2008). As a simple example, the eventual unified size, shape, and functional coherence of an entire ant colony cannot be explained or predicted by observing the behavior of an individual ant (Johnson 2002).

In order to address increasing complexity and emergence at ascending levels of compositional complexity, a number of unique scientific specialties have been developed. Interestingly, as different specialties approach topics from different levels, each necessarily utilizes a unique set of questions, definitions, tools, and success criteria (Pave, 2006). To explore this, let’s use ‘measles’ as an example. At the cellular level, cytologists might map proteins at the viral/cell interface using crystallography in order to characterize the measles virus binding process (Tahara et al., 2008). At the tissue level, histologists might explore viral infolding using an eyepiece micrometer in order to characterize the susceptibility of different lymphoid tissues to measles (White & Boyd, 1973). At the organ level, post-mortem gross pathologists might directly measure necrosis patterns to characterize measles development and progression within the lung (Kascbula, Druker, & Kipps, 1983). At the population level, epidemiologists might map the prevalence of measles across a country using aggregate medical record data to characterize viral spread (Santoro et al., 1984).

These examples highlight the final concept that supports our framework: incommensurability. It’s clear that each of the above specialties represents a valid method of defining and exploring measles; however, it’s equally clear that each specialty is unique and difficult to integrate with the others. This is one of the foundations of incommensurability (Feyerabend, 1962; Kuhn, 1969). This concept is perhaps best explained via three statements:

1) Different paradigms are built upon different assumption concerning what constitutes a ‘valid’ scientific question and solution.

2) How individuals interpret data is influenced by the baseline assumptions of each paradigm.

3) As the methods and vocabulary utilized within different paradigms are unique, such paradigms cannot be meaningfully compared.

Though incommensurability was developed to explore conceptual evolution within scientific fields, replacing ‘paradigm’ with ‘level’ reveals why work between different specialties is largely independent. As noted above, researchers at each level must necessarily use a unique set of questions (assumptions), definitions (vocabulary), tools (methods), and success criteria (solutions) – accordingly, work within each level is incommensurable with work at other levels.
It is important to note, though, that incommensurability does negate conceptual translation. Most specialties are built upon the same larger environmental references (eg - germ-theory of disease) and examine the same topic (eg – measles). Accordingly, it is possible to conceptually contrast work conducted at different levels to demonstrate findings are non-contradictory – even if said findings are not directly comparable.

Taken together, these three key concepts can be combined to formulate the following: levels-of-organization represent a step-wise increase of compositional complexity. This increase leads to emergent properties unpredictable by preceding levels which require unique language, tools, data, and success criteria to explicate. Due to this utilization of different presumptions, vocabularies, methods, and solutions, unique levels-of-organization are incommensurable (Fodor, 1974; Rohrlich, 2004; Rosenberg, 1994; Wimsatt, 1994; Oberheim & Hoyningen-Huene, 2009).

**Prescriptive Translation between Incommensurable Levels-of-Organization**

The utilization of incommensurable methodologies and explanations imposes a limitation on prescriptive translation between different levels - and the difficulty in applying laboratory research to the classroom is symptomatic of what happens when this limitation is not abided by. More specifically, although it is possible to generate prescriptive translation between adjacent levels, this can only be achieved by accepting several unproven (and, largely, un-provable) assumptions (Atlan, 1993). Returning to measles – it’s possible that knowledge of viral binding at the receptors of a single cell may be useful for someone trying to characterize cellular-membrane fusion within a tissue (composed of thousands of cells). However, in order for the former to influence the latter, a number of assumptions must be made and accepted: for instance, that the extracellular environment created by millions of competition/cooperation cells won’t dramatically change membrane receptor sensitivity or that isolated cell behavior won’t change when joined into a cellular matrix. It is conceivable that, at some point in the future, we will be able to measure the activity of millions of individual cells simultaneously without a loss of fidelity – however, until that time, the acceptance of these assumptions is needed to fill in the gaps between adjacent levels.

From this, it’s clear that prescriptive translation between non-adjacent levels becomes risky as the weight and number of assumptions grows - however, of far more importance, the emergence of specific properties at each level unpredictable by preceding levels ultimately makes non-adjacent prescriptive translation deficient (Atlan, 1993; Mazzocchi, 2008). As an example, researchers interested in exploring the workings of single, isolated cell are unconcerned with and cannot speak to the properties that emerge when many cells join together to form a tissue (eg – permeability, elasticity, contractibility, etc.). However, it is precisely these properties that may
influence researchers interested in elucidating how different tissues work in tandem to create an organ. Similarly, properties irrelevant to and unpredictable by researchers examining tissues that emerge at the level of the organ (e.g., function, chemical production, structure, etc.) are precisely those properties researchers interested in exploring how different organs build into an organ complex may find of prescriptive utility. Accordingly, prescriptive translation between non-adjacent levels is ultimately meaningless as it fails to account for integral properties which emerge at intervening levels.

As this is a rather important point, perhaps it is worth looking at a more specific example. It’s possible to see how the process by which measles binds to a single epithelial cell may be of practical value to one interested in elucidating how measles spread across larger epithelial tissues (adjacent levels). However, as we ascend to higher levels, the practical value of viral binding specifics becomes less clear. For instance, of what practical value are the specifics of epithelial cell binding to researchers interested in describing the presentation of measles across the skin (composed of many different cell and tissue types), across the nervous system, across the entire human body, or across a whole country of human bodies (non-adjacent levels)? Of practical value to researchers at each level are those properties which emerge at the immediately preceding level (Huneman, 2008) – such that the researcher interested in the population-wide prevalence of measles may find some prescriptive use in the tools used by and conclusions drawn from a researcher describing the gross symptomology of measles within an individual. Again, viral binding may confer conceptual and/or functional translation to non-adjacent levels; but our only concern here is prescriptive translation.

Interestingly, it is through the consideration of accounting for emergent properties at ascending levels that the method of how to prescriptively translate between non-adjacent levels presents itself: namely, via step-wise prescriptive translation through all intermediary levels. More specifically, it is possible cell research may prescriptively influence tissue research (so long as certain assumptions are accepted) and it’s possible tissue research may prescriptively influence organ research (again, so long as certain assumptions are accepted). Accordingly, although direct prescriptive translation between the cellular and organ level will be inadequate (as properties that emerge at the tissue level will be unaccounted for), prescriptive translation can be undertaken between the cell/tissue and tissue/organ levels, thereby forming an inclusive and comprehensive path between levels.

Although this idea may seem simple and obvious, it is of paramount importance: when attempting to prescriptively translate between non-adjacent levels-of-organization, one must always and completely traverse each intermediary level. This step-wise ascension is the only method whereby properties that emerge at each level can be accounted for and ideas from non-adjacent levels can form a tentative prescriptive relationship.
Prescriptive Translation in the Science of Learning

The primary research fields that constitute SoL are neuroscience, psychology, and education, though it is recognized here that there are other disciplines involved. If we organize these unique fields into a compositional schema, we arrive at 5 unique organizational levels.

<INSERT TABLE 1.1>

Since its inception, the learning sciences have been rife with debate concerning the prescriptive translation of neuroscience to education, with many calling the endeavor difficult, if not impossible (Bruer, 1997; Varma, McCandliss, & Schwartz, 2008; Hruby, 2012; Byrnes & Vu, 2015). From this framework, we clearly see why: namely, neuroscience and education are non-adjacent levels and are compositionally separated by psychology (at a minimum). This means that any attempt to prescriptively translate directly between any level of neuroscience and education necessarily ignores and cannot predict or account for important properties that emerge at the psychological level – and, as we’ve seen above, it is precisely these properties which likely will confer prescriptive utility at the educational level.

To better appreciate this, let’s use the scientific elucidation of language as an example. The primary focus of many linguistic researchers at the cognitive/behavioral (c/b) neuroscience level is to map different language functions to specific brain areas. In order to do this, they must decompose language into its constituent parts (eg – verb comprehension), construct an artificial task that isolates and targets an isolated part (eg – read aloud 100 unrelated, context-free verbs), and ask an individual to perform said task whilst measuring an indirect correlate of neural activity in an artificial, highly-controlled environment (eg – blood oxygen level patterns as measured whilst lying prone in a 70cm bore hole: for review: Vigliocco, Vinson, Druks, Barber, & Cappa, 2011).

Moving to the next level, the primary focus of many linguistic researchers at the c/b psychology level is to determine how the constituent parts of language re-combine to create a complete and meaningful ‘language’. Though it’s possible to see how the conclusions derived by linguistic c/b neuroscientists may prescriptively influence linguistic c/b psychologists, several unproven (and un-provable) assumptions must be accepted: for example, that brain areas active during an isolated task will behave similarly during amalgamated network activation, that isolated behavioral functions will not change dramatically when integrated into larger behavioral sets, that activation patterns will not undergo important shifts in response to varied environmental influences, etc. (Chomsky, 1995).
If one were to ignore c/b psychology and try simply to prescriptively translate findings from c/b neuroscience into education, not only would the amount and severity of the assumptions increase, but also utility would disappear. As noted above, in order for linguistic c/b neuroscientists to undertake their research, they must decompose language, create an artificial task, and measure neural activity in an unnatural environment. By necessity, this method eliminates all competing environmental factors and removes any integrated utility/meaning from language – however, these are the very things one must account for in order to consider and impact language learning in the classroom (Gibbons, 2002). Interestingly, environmental influences and integrated linguistic utility/meaning are reconstituted at the c/b psychology level, thereby outlining a path for prescriptive utility.

How does knowledge of occipital neuronal activation patterns in response to the visual perception of the letter “T” prescriptively influence an educator attempting to teach 20 students how to read? Of more utility to this educator would be the knowledge that successful reading requires the successful integration of visual letter identification with auditory phonemic discrimination in order to derive meaning: a larger behavioral set that emerges within the psychological level and can be elucidated using c/b psychological methods (Chall, 1996). Similarly, of what prescriptive utility is the understanding that sensory neurons activate during adjective generation to an educator trying to help a class learn how to speak French? Again, of more utility to this educator is the understanding that novel language learning requires the successful integration of object recognition, identification, and conceptual mapping: a larger behavioral set that emerges within the psychological level and can be elucidated using c/b psychological methods (Barsalou, Kyle, Simmons, Barbey, & Wilson, 2003).

Again – according to this framework, prescriptive translation requires a step-wise transition between adjacent levels-of-organization. Any attempt to ‘skip’ or otherwise omit intermediary levels will ultimately lead to ineffective prescriptive translation as it ignores key emergent properties.

Using the Framework to Resolve the ‘Brain-Training’ Debate

Over the last decade, there has been an ongoing debate in the science of learning concerning the role and efficacy of ‘brain training’ programs and games. In late 2014, a scientific consensus statement published by the Stanford Center for Longevity (A Consensus on the Brain Training Industry, 2014) and signed by 65 researchers concluded that brain-training conferred only narrow, short-lived effects and was ultimately ineffective. Interestingly, it took only a couple months before a counter-scientific consensus statement was published (Cognitive Training Data, 2014). This statement, signed by 117 researchers, argued that there was irrefutable evidence that brain-training confers measurable and meaningful effects. (Note: each statement included a
number of non-researcher signatories – including marketing and business developers – who were omitted from these calculations).

Although this issue may seem intractable, application of the above framework actually clarifies where the discrepancy lies. More specifically, if one divvies the signatories of each consensus statement into their corresponding ‘level’ of research, an interesting and telling pattern emerges. With regards to the anti brain training statement, of the 65 signatories, 83% conduct research at either the c/b psychology or education levels, whilst only 17% conduct research at the c/b neuroscience level. Conversely, with regards to the pro brain training statement, of the 117 signatories, 75% conduct research at c/b neuroscience level, whilst only 25% conduct research at the c/b psychology or education levels.

This suggests that brain training likely does work when the questions of interest (eg – do functional brain patterns change?) and outcome measures (eg – electroencephalography) are derived from the neurological levels. However, this also suggests that brain training does not work when the questions of interest (eg – does training confer far transfer?) and outcome measures (eg – performance on a secondary memory tasks) are derived from behavioral or educational levels. In other words, both sets of researchers are likely correct – they are merely arguing from different levels of the framework.

Of importance for our purposes is that this occurrence demonstrates well the path of prescriptive translation. When utilizing the language, methods, tools, and outcomes of c/b neuroscience, brain training programs and games appear to be effective (in that they modulate network activity). However, we now see that any attempt at prescriptive translation of this information for use at the educational level would ultimately have failed, due to emergence and incommensurability. Rather, in order to make sense of this data, the first step was to prescriptively translate this information into the c/b psychology level. It was here where evidence revealed that changes in neural function engendered by brain training do not confer lasting or transferable changes in behavior – let alone educationally relevant behavior. In other words, unpredictable properties which emerged at the c/b psychology level (namely, larger behavioral patterns) and the adoption of a new set of language, methods, tools, and outcomes made the potential prescriptive utility of information gleaned at a preceding level obsolete – though brain change was extant, it did not scale up to meaningful behavioral change. However, had brain training showed an important effect at the c/b psychological level, prescriptive translation for education would not have been complete. Rather, research within the classroom would have been required to account for any unpredictable properties to emerge at the socio-cultural educational level (eg – environmental influences).

What is likely to have come from research in the classroom is a reinforcement of the importance that needs to be placed on the context in which students are learning. Brain training provides an example of a digital learning environment that can be used across multiple settings. The extensive history of research on the use of educational technologies, of which digital brain
training tools broadly fit within, is that the medium is not as important as the pedagogy that sits around the tool (Clark, 2014). For teachers then, prescriptive translation must take into account the socio-cultural aspects of the learning setting in order for tools like those developed as part of the brain training trend to be used effectively within context, not in a context free, inert manner. The inert nature of brain training programs is likely part of the reason why they have largely failed to have any clear or predictable impact on learning in real world settings over a long term.

The Difference between Medical and Educational Translation

In the past, several authors have drawn a parallel between medical and educational translation (Sousa, 2010; Atherton & Diket, 2005; Thomas, 2013; Hale, 2015). More specifically, there is a well established system by which research from varied levels translates up to a set of procedures and or processes medical professionals can utilize. Several individuals have argued that this established medical model can serve as a model for proper and effective educational translation. Unfortunately, there is a large and important difference between these two fields that makes this comparison untenable.

In many respects, the primary outcome of medicine (morbidity/mortality) can be considered as binary: patients are either ill/well or alive/dead. For this reason, within medicine, the ultimate goal remains unchanged across different levels-of-organization. Researchers tackling the problem of disease at different levels (cells, tissues, organs, etc.) all have the same end-point: to ensure survival of the individual (well/alive). This makes the step-wise advance of prescriptive translation relatively straightforward; namely, any endeavor which combats disease at one level without negatively impacting overall morbidity/mortality will be adopted and progressed.

As an example, imagine if a cytologist developed a method to effectively kill viral infections within blood cells – but, in order for this method to work, all other cell types must be killed. In a purely scientific context, this method would be considered a breakthrough as it could be used to further the goals of biological science (for instance, elucidating the mechanisms by which blood cells multiply, protect themselves, and/or interact with foreign viral bodies). However, in a medical context, this method would be considered deficient as it does not further the goal of well/alive.

Unlike the binary-natured medical outcome, educational outcomes are multidimensional and multifaceted in nature. Beyond simple the retention of information (which may, rightly, be considered binary), the ultimate goals of education encompass varying degrees of a number of universal skills (eg - comprehension, synthesizing, innovation, etc.) and socially specific considerations (eg - ethics, citizenship, confidence, etc.). This complexity is, perhaps, why
adopting the medical model in education has been ineffective and why there has been no clear process for prescriptive translation in SoL to date.

It is worth noting that, when we utilized measles as an exemplar in earlier sections of this chapter, we purposely did not broach the subject of medical treatment. Our reason for this should now be clear. We confined our discussion to the scientific characterization of measles across different levels-of-organization as this more closely resembles the process of prescriptive educational translation than the medical treatment of measles.

**What this Means for Science of Learning Researchers**

Arguably the most apparent ramification of incommensurable levels-of-organization for researchers in the science of learning is the outlining of a path by which prescriptive translation can be pursued. During the last several years, a tremendous amount of resources and time have been expended considering the direct applicability of neuroscience to education. However, as this framework demonstrates, attempted prescriptive translation between non-adjacent levels is simply not a meaningful endeavor as it ignores emergence at intermediary levels. This is not only true in the SoL, but it’s also true within every multidisciplinary applied scientific pursuit.

Additionally, incommensurable levels-of-organization should help alleviate the pressure some researchers feel to apply their findings to non-adjacent levels. In this context, the current excitement concerning direct application of neuroscience in the classroom is especially important to consider, as this practice leads to the development of overly-simplified models and is the ultimate foundation of neuro-myths. These models also generally fail to provide teachers with sufficient flexibility for them to make informed decisions about how best to apply the recommendations to their own classroom setting. Perhaps, with this framework, it will be easier to justify the specification of prescriptive translation between adjacent layers in a bid to establish more comprehensive ideas for the classroom (as is the aim of this book).

Finally, the elucidation of levels-of-organization may also prove beneficial to the organization of science of learning labs and journals. For instance, in order to guide prescriptive translation, larger mind/brain/education labs may consider organizing space so as to ensure those researchers at adjacent levels have more direct contact. Similarly, science of learning themed journals may opt to organize articles according to the organizational levels. This practice may help researchers and practitioners at all levels quickly and easily locate relevant articles from their own and adjacent levels.

**Conclusion**
There is a great deal of excitement and expectation surrounding SoL – as there should be! The concept of improving the education and lives of future generations via the application of multidisciplinary empirical research is incredible. However, as with any nascent endeavor, establishing a foundational framework to ensure development and translation occurs in the strongest and most beneficial manner is of paramount importance. We believe the frame presented here represents the most inclusive and comprehensive way forward and will ultimately lead to quicker, more comprehensive, and more successful prescriptive translation between the laboratory and the classroom.

From the Laboratory to the Classroom

Recently, several SoL researchers have put forward the argument that, in order for educators to improve their efficacy, they need to become more knowledgeable about neuroscience and the brain (Busso & Pollack, 2014; Dekker, Lee, Howard-Jones, & Jolles, 2012; Devonshire & Dommett, 2010). The levels-of-organization framework helps illuminate the mistake with argument. Just as a jeweler need not comprehend the molecular bonding patterns of silver atoms in order to craft an engagement ring, or a chef need not comprehend how flavors are transduced into electrical signals at the tongue in order to prepare a wholesome meal – an educator need not comprehend how neurons or neural networks function in order to effectively teach students. Education is a behavioral activity undertaken within a socio-cultural context. The assumptions, vocabulary, methods, and solutions important to education depend upon and reside within properties that emerge above the level of neuroscience – therefore, the two fields are prescriptively separate. This does not mean knowledge of neuroscience cannot inspire (conceptual translation) or assist (functional translation) certain educators – it simply means that intimate knowledge of the brain is not a necessity and will not directly confer successful educational practices (prescriptive translation).

In addition, educators are currently being inundated with programs designed to influence and nurture the brain. With this new framework, the importance and veracity of these programs can be put into perspective. More specifically, ‘brain change’ is not an outcome we, as educators, can readily measure in the classroom – rather, we are rightly confined to utilizing and measuring behavioral and social outcomes. Accordingly, of importance when being presented with novel programs is not whether they scale-down to confer brain change, but whether they scale-up to confer meaningful, educationally relevant behavioral change. In short, educators do not need to be concerned with ‘brain’ claims; rather, they need only to be concerned with behavioral and educational claims and how to make the best possible decisions about what will work best in their practice context.
References


