MBE Final Report

07/26/06
MBE final report

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Task description

This project was guided by two primary objectives. We were asked to:

• assess and describe the developmental progress made by students in Mind, Brain, and Education;
and
• describe the relation between students’ cognitive developmental level of performance and their understanding of interdisciplinarity in Mind, Brain, and Education.

Overview

To achieve the above objectives, we analyzed the developmental (complexity) levels and conceptual content of 46 students’ performances on two essays that were part of their regular MBE coursework. Although both essays required respondents to employ biological, cognitive, and educational perspectives (the MBE perspectives), essay 1 asked students to make sense of a non-standard student profile, whereas essay 2 asked students to critique a theoretical statement concerning neural-networks and human learning processes. As a result of this difference in focus, there was very little common content across the two essays. The dissimilarity of the essays did not pose any problems for the complexity analysis itself, but they did pose important problems for our analyses of conceptual and structural growth.

First, because the essays focused on different topics, there were only 4 cases in which students wrote twice on the same theme. This seriously restricted our ability to describe conceptual change from time 1 to time 2. Second, the final essay was intrinsically more demanding than the first. While solutions to the essay problems had no upper limit with regard to complexity, there were differences in the lowest possible understanding. That is, the task of essay 1 could be understood and approached at abstract mappings. To complete essay 1, a student must only have grasped the non-standard student profile—the idea that a student does well in school even though he has a learning disability and does poorly on standardized tests—and coordinated this understanding with the three MBE perspectives. At abstract mappings, students could simply perform one linear coordination at a time. Essay 2, on the other hand, required at least abstract systems. Students needed to understand (1) the idea that neural networks extract rules from examples and (2) what this might suggest about human learning processes. These highly abstract sets of concepts then had to be coordinated with the three MBE perspectives. A student who failed to understand neural networks at an abstract systems level could not sensibly approach this task. This difference in complexity between the two essays may have contributed to a difference in the complexity of responses at times 1 and 2, and may account for some of the performances that were at a lower level at time 2 than at time 1 (see below).

Despite the disappointing prospects regarding pre-post comparisons, both essays were rich with content and yielded interesting findings. First, many students demonstrated developmental progress; second we were able to describe developmental sequences for the 6 major themes identified in the essays; and third the 4 pre-post comparisons we were able to make reveal interesting patterns of concept acquisition and structuring.

Complexity analysis

Each of 92 essays (46 from time 1 and 46 from time 2) was awarded a holistic complexity level score using the 5 phase version of the Lectical™ Assessment System (LAS) (Dawson, 2006). The analyst was blind to the identities of the students, but not to the time of testing.

At time 1, complexity level scores ranged from 25 (transition out of abstract mappings) to 32 (unelaborated single principles), M = 27.85, SD = 1.44. At time 2, complexity level scores ranged from 25 (transition out of abstract mappings) to 33 (elaborated single principles), M = 28.37, SD = 1.58. Ten students demonstrated no measurable developmental progress, 13 exhibited regressions, and 22 demonstrated developmental progress. Table 1 shows the distributions of the difference scores.
Table 1: Frequencies for difference scores

<table>
<thead>
<tr>
<th>Difference</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2.00</td>
<td>4</td>
</tr>
<tr>
<td>-1.00</td>
<td>9</td>
</tr>
<tr>
<td>.00</td>
<td>10</td>
</tr>
<tr>
<td>1.00</td>
<td>10</td>
</tr>
<tr>
<td>2.00</td>
<td>8</td>
</tr>
<tr>
<td>3.00</td>
<td>4</td>
</tr>
<tr>
<td>4.00</td>
<td>1</td>
</tr>
</tbody>
</table>

As shown in Table 2, the difference between mean complexity scores at times 1 and 2 was statistically significant, with an average growth of about 1/10 of a complexity level. But this is not the whole story. Interestingly, as revealed in Table 3, there was more growth for students who performed in the transition to abstract systems at time 1 than for those who were already performing at abstract systems at time 1. Separate t-tests for these two groups show no growth for students performing at abstract systems at time 1 (Table 4) and growth averaging almost 2/5 of a complexity level for students performing at the transition to abstract systems at time 1 (Table 5). The low average growth for students in the first group can largely be explained by a high rate of regression; 63% of the students in this group performed at a lower level at time 2 than at time 1, whereas none of the students who performed in the transition to abstract systems at time 1 performed at a lower level at time 2.

We know from numerous modeling studies that individuals appear to spend less time in developmental transitions than in periods of consolidation (Dawson, 2002a, 2002b; Dawson-Tunik, 2006a, 2006b). In other words, transitions seem to be easier to get through than they are to get to. This phenomenon is consistent with a dynamic systems model of cognitive development, in which transitions are modeled as catastrophes, or relatively rapid disruptions of the equilibrium of a system that are resolved through the reorganization of that system. Although this model offers an explanation for the pattern of growth observed in this sample, it does nothing to explain the pattern of regression. Moreover, the pattern of regression, by itself, explains the differences in growth across the transitional and consolidating students. We suspect that the correct explanation for the observed patterns is in some way related to the differences between the essays.

Table 2: T-Test of differences in means at time 1 and time 2

Paired Samples Statistics

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAS Time 1</td>
<td>27.83</td>
<td>46</td>
<td>1.450</td>
<td>.214</td>
</tr>
<tr>
<td>LAS Time 2</td>
<td>28.37</td>
<td>46</td>
<td>1.583</td>
<td>.233</td>
</tr>
</tbody>
</table>

Paired Samples Correlations

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Correlation</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAS Time 1 &amp; LAS Time 2</td>
<td>46</td>
<td>.493</td>
<td>.000</td>
</tr>
</tbody>
</table>

Paired Samples Test

<table>
<thead>
<tr>
<th></th>
<th>Paired Differences Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>t</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower</td>
</tr>
<tr>
<td>LAS Time 1 – LAS Time 2</td>
<td>-.54</td>
<td>1.531</td>
<td>.226</td>
<td>-1.00</td>
</tr>
</tbody>
</table>

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Table 3: Frequencies for difference scores by complexity level at time 1

<table>
<thead>
<tr>
<th>Difference</th>
<th>Transition out of abstract mappings</th>
<th>Transition into abstract systems</th>
<th>Unelaborated abstract systems</th>
<th>Elaborated abstract systems</th>
<th>Highly elaborated abstract systems</th>
<th>Transition out of abstract systems</th>
<th>Unelaborated single principles</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2.00</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1.00</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.00</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.00</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.00</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.00</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4: T-Test of differences in means at time one and time 2 for transitional performances 25 and 26

Paired Samples Statistics

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAS Time 1</td>
<td>25.75</td>
<td>8</td>
<td>.463</td>
<td>.164</td>
</tr>
<tr>
<td>LAS Time 2</td>
<td>27.63</td>
<td>8</td>
<td>1.598</td>
<td>.565</td>
</tr>
</tbody>
</table>

Paired Samples Correlations

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Correlation</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAS Time 1 &amp; LAS Time 2</td>
<td>8</td>
<td>.435</td>
<td>.282</td>
</tr>
</tbody>
</table>

Paired Samples Test

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>95% Confidence Interval of the Difference</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAS Time 1 - LAS Time 2</td>
<td>-1.88</td>
<td>1.458</td>
<td>.515</td>
<td>-3.09 - .66</td>
<td>-3.638</td>
<td>7</td>
<td>.008</td>
</tr>
</tbody>
</table>

Overall, the growth patterns observed here are consistent with past research (Dawson-Tunik & Stein, 2004; Dawson-Tunik & Stein, 2006; Dawson-Tunik & Stein, manuscript submitted for publication) and the predictions of skill theory (Fischer & Bidell, 2006). However, we observed more regressions than we have in the past and suspect that we may have seen fewer examples of regression if the essays written at times 1 and 2 had been more similar in difficulty.
Table 5: T-Test of differences in means at time 1 and time 2 for abstract systems performances 27, 28, and 29

**Paired Samples Statistics**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAS Time 1</td>
<td>27.88</td>
<td>32</td>
<td>.751</td>
<td>.133</td>
</tr>
<tr>
<td>LAS Time 2</td>
<td>28.25</td>
<td>32</td>
<td>1.414</td>
<td>.250</td>
</tr>
</tbody>
</table>

**Paired Samples Correlations**

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Correlation</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAS Time 1 &amp; LAS Time 2</td>
<td>32</td>
<td>.182</td>
<td>.318</td>
</tr>
</tbody>
</table>

**Paired Samples Test**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>95% Confidence Interval of the Difference</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAS Time 1 - LAS Time 2</td>
<td>-.38</td>
<td>1.476</td>
<td>.261</td>
<td>-.91</td>
<td>-.16</td>
<td>31</td>
<td>.161</td>
</tr>
</tbody>
</table>
Content analysis

In this section, we present the results of a series of content analyses of major themes in essays 1 and 2. We provide elaborated accounts for only the four themes from essay 1. The themes from essay 2 were more varied and we were unable to learn enough about any one theme to provide an elaborated account.

The results of the analysis are presented in two forms: (1) as tables consisting of descriptions and exemplars for each complexity phase represented in the data; and (2) as concept maps, showing the structure and elements of idealized arguments for each phase. These tables and maps should be of use to teaching assistants, who are likely to encounter these themes frequently within the MBE context.

Method

Constructing sequences

A knowledge domain is a broad set of related concepts and competencies. Domains are made up of thematic strands, which are topics or themes of central importance to the domain. For example, the domain of leadership, contains at least the following thematic strands: ethics, critical thinking, social skills, communication skills, leadership style, emotions, cognition, personality. This means reasoning about leadership, e.g. judgments made by or about leaders, has been shown to involve at least those thematic strands. The strands are differentiated in so far as each has a relatively unique developmental logic, trajectory, and pace. It is possible, for example, to be a leader whose judgments are highly developed with regards to critical thinking but poorly developed with regards to social skills. So understanding how development proceeds in a domain requires understanding how development proceeds in each of its thematic strands. Gaining such an understanding can, in part, be accomplished by rationally reconstructing a developmental sequence for each strand.

A sequence is a description of reasoning along a thematic strand as it develops across some subset of Lectical Levels. Habermas (1990) has suggested that descriptions such as these should be understood as rational reconstructions. Here he is pointing to the common core of genetic structuralist renderings of the development of capabilities, such as those offered by Piaget and Kohlberg. Rational reconstructions result in potentially universal accounts of how a capability develops across a series of structurally defined stages. So a sequence is a rational reconstruction of how a particular thematic strand develops. As such it is the result of (1) a formal structural account of developmental stages, provided by the Lectical™ Assessment System; (2) a method for content analysis that can identify thematic strands; and (3) an inductive procedure enabling the construction of general descriptions of reasoning from a limited data set of examples.

Here I will describe the analyses and inductions undertaken by the authors here, and in other research efforts, to rationally reconstruction developmental sequences.

Developmental and thematic content analyses

To begin, a data set consisting of examples of reasoning in a given domain must be both scored for developmental level and coded for thematic stands. Typically these two analyses are done in isolation. However, in this study one analyst did both analyses.

The scoring procedure has been explained in detail at www.lectica.info. It should be noted that a clear understanding of the structural properties of the stages is an essential part of the inductive procedure discussed below. That is, without a working knowledge of the Lectical™ Assessment System's scoring criteria much of what is required to accurately extrapolate general descriptions of reasoning at each level is prohibitively difficult, if not impossible. As explained below, offering such descriptions requires knowing both what is possible at a given level (e.g. in terms of structural limitations) and what has been found (e.g. what the data offer).

The coding that results in the identification of thematic strands involves undertaking a detailed inventory of the concepts that appear in the data. Each protocol must be categorized according to what is discussed therein. For example, a protocol discussing fairness as an important consideration would be labeled as such; and so grouped with other protocols discussing fairness. After a complete inventory has been compiled themes can be identified.
Themes are those broad concepts that appear as prominent or central in any given protocol. That is, themes are not ideas but topics. For example, here is sample from a protocol:

Cognitive development is not a ladder as Piaget's stage theory suggests, but a web with many interconnected strands (Fischer, lecture, Skill Theory). Each person has a unique web of development. Due to his dyslexia, Jeremy's web is underdeveloped in linguistic areas, but his web may be highly developed in musical or other areas.

Whereas many concepts are discussed (such as, dyslexia, Piaget's stage theory, etc.) the theme is cognitive development. It is the topic of the example as opposed to an idea found therein. Of course, it's sometimes difficult to differentiate between topics and ideas, or themes and concepts. Some single protocols have multiple themes. So, the procedure of identifying themes typically starts out with an over abundance of identified themes, out of which those most central can be distilled.

Moreover, only some themes can serve as data for the rational reconstruction of sequences. These are themes found consistently and recurrently across the majority of the protocols and across some sub-set of developmental levels. The later point is critical. When theme-identifying-analyses have been carried out independently of developmental analyses, useful themes can only be identified when the results of the two analyses are brought together. And it is when these results are brought together and the relevant themes have been identified that the inductive procedure begins. By superimposing the result of thematic analyses over top of the developmental analyses a picture of the sequences present in the data emerges.

Before getting to this, the following should be noted: In this study a potential list of themes was identified before the essays were read. This was possible because of the familiarity of the researchers with the domain. But, of the potential themes suggested, not all were found. When we undertook the procedure discussed above, some suggested themes were proven unfounded, while other themes were justified as relevant and useful.

**Inductive construction of descriptions**

The developmental analyses place each protocol at a single location along the developmental continuum. The thematic content analyses identify the thematic strands as they occur in each protocol. When these two forms of analysis are brought together they result in readily accessible examples of how themes are thought at various developmental levels. It is from these examples that descriptions of reasoning at each level can be produced. The flow chart below outlines the process to this point.

As should be clear from the discussion thus far, by the time the inductive construction of descriptions is undertaken the data have been analyzed from two different perspectives. The inductive procedure itself involves (1) organizing the results of these analyses and (2) extrapolating generalized descriptions from these results.

The organization can take many forms. Typically a table is complied of examples from each theme, which are sorted developmentally. This table is, in effect, a sequence of examples. This allows all the examples at a particular level from a particular theme to be viewed at a glance. Reading over a table organized in this manner allows for carefully comparing and contrasting sets of examples from different levels. This supplies the information out of which more general descriptions can be constructed.
Figure 1: Flow chart displaying differentiation and re-integration during analyses.

The descriptions that make up a sequence (see those offered in this report) follow a specific format. The generalizations upon which they are based follow strict guidelines. Each description of reasoning at a particular level within a particular theme is composed of (1) a structural characterization of the level; (2) an idealized example of common reasons and ideas offered at this level; (3) an account of several general properties of the content found at this level. Each such description is accompanied by a full-
length sample from the data. To construct these three components of the descriptions, several questions must be asked of the data. Answering these questions allows one to generalize about properties of reasoning at a given level within a given theme. The questions are:

1. What can be found that is common across the set of examples at this level? How common is it? Which examples have it, etc.?
2. What is unique about the set of examples at this level when compared to the level immediately below it? What is unique about the set of examples at this level when compared to the level immediately above it?
3. What are the most common ideas in the set of examples at this level that are not found in either the level above or below it?
4. Given the structural properties of this level, and the answers to questions 1-3, what are the conceptions that (a) may possibly be found at this level, (b) are likely to be found at this level, and (c) are actually are found at this level?

These questions serve to guide the construction of generalizations during the process of crafting a particular description. Question 4 is of primary importance because it highlights the centrality of the formal structural properties outlined by the Lectical™ Assessment System.

**Concept map construction**

Concept maps serve primarily as heuristics. There is no precise formula for their construction. However, there are clearly better and worse concept maps. They are in essence graphical representations of reasoning processes. But they aim to make these processes clearer than they typically are when only language and grammar are employed, e.g. prose writing. Guided by their functions as heuristics, good concept maps should be constructed with (1) clarity and (2) structural simplicity. I will take each one of these in turn.

1. **Clarity**: the maps used in this study employ as few elements as possible: lines, arrows, and rectangles as well as regular and italicized text. Each is employed constantly across all the maps. **Squares** represent conceptual elements. These elements need not be single words; typically they are groups of words. However, each conceptual element should be a unit that makes reference to others via lines. **Lines** represent connections between conceptual elements; typically these connections relate a group of elements that form a proposition. Arrows indicate the direction of the argument. Important connection words and most vowels are not enclosed in boxes. Vowels are italicized.

2. **Structural simplicity**: The most basic logical properties of a sample of reasoning should be presented as clearly as possible. This is why the connection words and verbs are isolated. This is also why the size of the conceptual elements is not fully specified: they should be as big or as small as needed to represent the structural properties of the argument as simply as possible.

**Major themes in essay 1**

There was a great deal of homogeneity in the content of student's approaches to essay 1. This allowed us to identify four strong themes, all of which yielded detailed sequences. Here we describe the conceptions that fall under each theme and describe the form and content of reasoning about each theme in tables and maps.

**Sequence for conceptions about the relation between nature and nurture**

This theme deals with the relation between genetics and environment, with respect to certain educationally relevant traits. The discussion revolves around learning disabilities. Conceptions range from simple statements that both nature and nurture play a role in development, to more complex specifications of the dynamics of environmental impacts on gene expression.
Table 6: Conceptions of the relation between nature and nurture by complexity phase

<table>
<thead>
<tr>
<th>Complexity level</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
</table>
| Transition into abstract systems       | At this level, conceptions about the relationship between nature and nurture involve the coordination of sets of abstractions. Typically nature is conceived as a set of abstractions about genetics, and nurture is conceived as a set of abstractions about environments, upbringing, or education. These two sets of abstractions are then related. One finds ideas like: *some traits are inherited via genetic transmission; they are passed on from parent to offspring. However, the experiences one has while growing are just as important in shaping development.*  
Typically, the conceptions at this level amount to the conclusion that both nature and nurture are important, despite the fact that some traits (such as learning disabilities) are more the result of one than the other. Genes are discussed almost solely in terms of inheritance. Gene-environment interaction is sometimes mentioned, but never elaborated. | ...behavior traits are generally influenced by multiple genes and environmental factors (Plomin et al., 1997). The genes you inherit do not imply genetic determinism because the environment always plays a role in development. (Plomin et al., 1997). So even if you inherit a learning disability a supportive school environment could help with learning disabilities (38). |
| Unelaborated abstract systems          | At this level, conceptions about the relation between nature and nurture involve the elaboration and coordination of abstractions into multivariate structures. Multiple sets of abstractions about genetics are coordinated and then related to multiple sets of abstractions about environment, upbringing, or education. For example, one finds ideas like: *the appearance of inherited traits depend upon both genetic and environmental factors, because genes are not deterministic but rather rely upon environmental factors to trigger their expression.*  
At this level, nature and nurture begin to be seen as interdependent and not as opposing or contrasting forces. Both are needed to facilitate gene expression. Here we find the beginnings of conceptions about genetics and environment as being coordinated in light of a single process. At this level, the process is understood as interactive; conceptions oscillate between explaining heritability and explaining environmental effects on heritability. | This student presents us with a learning disability that has also been documented in close blood relatives. Although the obvious assumption is that the learning disability is genetic, it is improper to establish a single connection between biology and education based on genetics...Specifically, although the prevalence of learning disabilities in the family may suggest genetic links, the educational environment of the student may also affect the learning disability. Ridley (2003) writes about the concept of Nature via Nurture, suggesting that genes work through the environment. In the case of the student, a positive nurturing environment may have minimized the manifestation of the learning disability, thus explaining the exceptional grades despite the presence of a learning disability (26). |
<table>
<thead>
<tr>
<th>Complexity level</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elaborated abstract systems</td>
<td>At this level, conceptions about the relation between nature and nurture involve the construction of multivariate systems of abstractions. Reasoning entails the consistent employment of single terms built from multiple abstractions, such as experience-dependent gene expression in an enriched educational environment. For example, one finds statements like: genotypic profiles should be used to detect genetic risk factors that can in turn inform educational practices. The resulting targeted educational interventions should be aimed at positively shaping the expression of predisposed traits, such as learning disabilities. At this level, the gene and environment interaction is consistently unpacked in terms of several concepts describing this interaction. Here we find one process, the environmentally contingent processes of gene expression. This idea organizes increasingly differentiated accounts of human development.</td>
<td>A first step toward understanding the student's unique abilities, and connections between the seemingly mismatched aspects of his profile is to look at his situation through the lens of biology. One of the most salient aspects in terms of biology is the student's heritable learning disability. These genetic contributions, which point toward a sub-normal potential, only indicate what is, not what could be (Plomin, Defries, McLearn, &amp; Rutter, 1997). In order to fully understand the effects that learning disorders have, one must consider the neurological basis of the disorder, its effects on cognitive and performance abilities, and &quot;the role of experience in shaping brain development and genetics&quot; (p. 8) from a dynamic, interactive perspective (Fischer, Bernstein, &amp; Immordino-Yang, in press) (19).</td>
</tr>
<tr>
<td>Transition into single principles</td>
<td>At this level, conceptions about the relations between nature and nurture involve the organization of multivariate systems of abstractions. New conceptions entail unelaborated co-ordinations of abstract perspectives on genetics and environmental factors affecting gene expression, such as education. These perspectives subsume systems of abstractions. For example, one finds ideas like: a learning disability must be seen as the result of a dynamic interaction between genes, brain growth, and the learner's experiences in socio-cultural environments. The genetic components set a range of biological potentials, as some experience-dependent patterns of gene expressions will be triggered, but not others. Brain growth takes place in this context of genetic potentials and in the context of education, which as a set of specific experiences and challenges, serves to shape both the expression of genes and the growth of the brain. At this level, overarching views begin to emerge about how the genes/environment interaction should be understood. A variety of concepts are used to explicate the processes involved. These ideas are usually coordinated concepts from human development, neuroscience, and education. The resulting perspective begins to specify the role of genetics in the practice of education and the understanding of human development.</td>
<td>Wadsworth, Olsen, Pennington, &amp; DeFries (2000) examined the genetic etiology of learning disabilities and found that certain learning disabilities are heritable. The term &quot;heritability refers to the genetic contribution to individual differences (or variance)&quot; (Plomin, DeFries, McLearn, &amp; Rutter, 1997, p.82). Since the parent and sibling of the student both have learning disabilities, heritability is clearly playing a role in the development of this particular trait. However, it must be noted that, &quot;heritability does not imply genetic determinism&quot; (Plomin et. al., 1997, p.85). That is, environmental factors are an integral part of the process of gene expression. Kurt Fischer (2005) stated, &quot;a learning experience leads to changes in the particular genes activation&quot; (Fischer, lecture, 2005). Therefore, in this case, it might be best to conceptualize the genetic endowment as predisposing the student to develop a learning disability, while the environmental factors serve to actualize that potential by shaping and influencing the gene's expression (19).</td>
</tr>
<tr>
<td>Complexity level</td>
<td>Description</td>
<td>Example</td>
</tr>
<tr>
<td>------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Unelaborated</td>
<td>At this level, conceptions about the relations between nature and nurture involve the organization and coordination of multivariate systems of abstractions. This entails building arguments out of highly abstract perspectives in light of overarching generalizations and for the sake of principled conclusions. For example, at this level, distinct and elaborate theoretical views about genetics and education are brought together to justify particular statements or practical recommendations, as in: On the one hand, we can't divorce nature from nurture because even highly heritable traits are dependent upon certain facets of the environment to trigger their expression; so there is no genetic determinism. Yet, on the other hand, as a result of typical experiences encountered during the course of ontogenesis certain genetic profiles promote the growth of atypical functional organizations within the brain, sometimes, for example, affecting those regions most relevant for reading. So, it's not a matter of overriding nature via nurture but rather using behavioral genetics research to help in understanding the unique profiles of individual learners and to customize educational initiatives accordingly. At this level, accounts of the genes-environment interaction are wedded to overarching views about human development and the brain. The result is a biologically informed theoretical position about human development. Typically these views are used to make arguments and recommendations concerning specific educational issues, such as special education initiatives or the possibility of genetic profiling.</td>
<td>[No clear examples.] See Grigorenko lecture.</td>
</tr>
</tbody>
</table>
Figure 2: Maps of idealized conceptions of the relation between nature and nurture by complexity level

Transition into abstract systems
- some traits are inherited via genetic transmission passed on from parent to offspring however, experiences one has while growing are just as important in shaping development.

Unelaborated abstract systems
- the appearance of inherited traits depends upon genetic factors and environmental factors because they are not deterministic but rather rely upon to trigger their expression.

Elaborated abstract systems
- genotypic profiles should be used to detect genetic risk factors that can inform educational practices resulting in the expression of targeted educational interventions that should be aimed at positively shaping learning disabilities.
Transition into single principles

a learning disability
must be seen as the result of
dynamic interactions among
genes
learners' experiences in socio/cultural environments
brain growth
takes place
in context of genetic potentials
a set of specific experiences
and in the context of education
expression of genes
serves to shape
growth of the brain

Unelaborated single principles

there is no genetic determinism
we can't divorce nature from nurture
because highly heritable traits are dependent upon
certain facets of the environment to trigger their expression
it's not a matter of overriding nature via nurture
but rather, using behavioral genetics research
to help in understanding
the unique profiles of individual learners
Sequence for conceptions about the relation between dynamic development and assessments

This theme deals with the implications of a dynamic theory of cognitive development for the nature and worth of traditional assessments. The discussion revolves around critiques of the SAT from the perspective of skill theory, specifically the idea of functional and optimal levels of performance. Conceptions range from simple statements that the SAT doesn’t account for the variability of cognitive performances, to the contrasts between skill theory’s specification of the dynamic and contextual way in which skills are constructed and the context-insensitivity of traditional testing or the static conception of ability that informs most psychometric instruments.

Table 7: Conceptions of the relation between dynamic development and assessments by complexity phase

<table>
<thead>
<tr>
<th>Complexity level</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transition into abstract systems</td>
<td>At this level, conceptions about the relation between dynamic cognitive development and standardized tests involve the elaboration and coordination of abstractions into multivariate structures. Multiple sets of abstractions about cognitive development are coordinated and then related to multiple sets of abstractions about standardized tests. For example, the following idea is common at this level: students’ cognitive capabilities are variable, being sensitive to context and support. So, standardized tests, because they gauge only a single performance in a single context, do not accurately assess the full range of a student’s capabilities. Typically at this level, an idea, such as scaffolding, is explained. This is followed by a description of standardized testing practices focusing on testing context, for example, time or stress. The contrast serves to justify the idea that standardized tests don’t give students what they need to perform well, such as scaffolding, which means that these tests tend to assess functional rather than optimal level.</td>
<td></td>
</tr>
<tr>
<td>Unelaborated abstract systems</td>
<td>The standardized test environment generally does not allow for such scaffolding or support. Though such tests purport to pinpoint ability of thinking skills (College Board, SAT Reasoning Test Section) there is a range of cognitive ability shown by individuals at any time in their development. It is likely that lack of social support caused the student to perform at his functional rather than optimal level (Fischer 2005) in this situation. Fischer’s theory of dynamic skill development would account for this variability, explaining that, “a child who can solve an arithmetic problem...one day or in one situation frequently cannot solve the same problem the next day or in a different but apparently similar situation” (Fischer and Bidell 2005, p.1) (13).</td>
<td></td>
</tr>
<tr>
<td>Complexity level</td>
<td>Description</td>
<td>Example</td>
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<tr>
<td>------------------</td>
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</tr>
<tr>
<td>Elaborated abstract systems</td>
<td>At this level, conceptions about the relation between dynamic cognitive development and standardized tests involve the construction of multivariate systems of abstractions. Reasoning entails the consistent employment of single terms built from multiple abstractions, such as de-contextualized assessment techniques and developmentally appropriate curriculum. For example, one finds arguments like: the evidence for dynamic variability in cognitive developmental processes should alert us to how misleading standardized test scores can be. When scaffolded by teachers and peers a student can perform at an optimal level, sometimes a full stage above their unsupported performances. The standardized test environment provides no supports so evaluates only the functional level of student performance, thus providing only one perspective on the student's capabilities. If we consider the student's developmental range, the teacher may be able to more accurately assess what the student has learned.</td>
<td>Furthermore, as cognitive development grows dynamically and multidirectionally, competence in a skill occurs in developmental ranges and should be assessed in terms of developmental potentials with optimal and functional levels that are reached in direct proportion to the amount of scaffolding offered (Fischer, 2004). Our teenager likely flourished in his high school because much scaffolding in areas like lesson design, learning style accommodation, and classroom use of learning technologies were provided. Formative assessment like portfolios whereby learners are permitted to express what they have learnt in their product of choice, or a high support assessment such as a take-home examination assessing what has been learnt, permits the teenager to use the appropriate resources that would optimize [sic] performance and captures developmental range more accurately. Standardized testing with its lack of formative feedback so crucial in educative assessment offers no such scaffolding (Wiggins, 1998) nor reflection of the learner's developmental range. (41)</td>
</tr>
<tr>
<td>Transition into single principles</td>
<td>At this level, arguments about the relations between dynamic cognitive development and standardized tests involve the organization of multivariate systems of abstractions. Conceptions entail unelaborated coordinations of abstract perspectives on cognitive development and testing, perspectives subsuming systems of abstractions. For example, one finds conceptions like: Cognitive development proceeds via the active construction of skills in contexts, as capabilities gradually become increasingly complex overall, despite non-synchronous developmental progress across domains. This picture of cognitive development, as dynamic, contextual, and variable, conflicts with many of the assumptions held by traditional psychometrics, where intelligence is a stable entity within individuals regardless of contingencies affecting performance like levels of support or emotional state. Standardized tests working with these assumptions about intelligence miss some of the most important insights about the nature of learning, education, and cognition. At this level, descriptions of cognitive development tend towards theoretical generalizations integrating a variety of conceptions. Likewise, standardized tests are critiqued more often in terms of their form and underlying theoretical assumptions. Occasionally, these broad generalizations about cognitive development and testing serve to structure recommendations about how assessment ought to be used.</td>
<td>Acquisition of comprehensive understanding, however, is gradual and continuous, and developmental process involves factors like context, affective state, and support, at multiple levels (Fischer &amp; Bidell, 2005). S's consistent excellence suggests that this educational process has motivated him to be involved in structuring his own intellectual development, during which the school stands a good scaffold. Skill structure is no static and reductive indicator of competence but a dynamic construction by people acting in real contexts, actively associating and integrating various skills and experiences (Fischer &amp; Bidell, 2005, Fischer, Yan &amp; Stewart, 2002). This feature of inter-participation, integration and multi-direction in development necessarily highlights the role of external support for S to construct his own web of understanding and reorganization of knowledge for new situations, and to form and maintain functional level performance. With consistent high contextual support, using appropriate methods, S could reach optimal levels, which helps him in further consolidation and extension of learning. In neurophysiology such cognitive changes have already been shown to correlate with cortical activity spurts (Fischer et al, 2002). Then why did S score low on ST if he has developed so well? As a psychometric instrument, ST measures linear progression to higher performance on a forward single-direction sequence (Fischer &amp; Bidell, 2005), and cannot justly reflect the performance level of S's newly acquired skills, which may still be undergoing a gradual period of association and consolidation (Fischer et al, 2002) (18).</td>
</tr>
<tr>
<td>Unelaborated single principles</td>
<td>[No clear examples]</td>
<td>[No clear examples]</td>
</tr>
</tbody>
</table>
Figure 3: Maps of idealized conceptions of the relation between dynamic development and assessments by complexity phase

Unelaborated abstract systems

- Students' cognitive capabilities
  - Are
  - Sensitive to
    - Context
    - Support
  - Variable
  - Standardized tests
    - Do not accurately assess
      - The full range of a student's capabilities
        - Because they gauge only a single performance or single context

Elaborated abstract systems

- Evidence for dynamic variability in cognitive development processes
  - When scaffolded
    - By teachers and peers
      - Students
        - Can perform
          - At an optimal level, sometimes a full stage above their unsupported performances
            - Should alert us to how misleading standardized test scores can be
              - The standardized test environment
                - Provides
                  - No supports
                    - So
                      - Evaluates
                        - Only the functional level of student performance
                          - Providing
                            - Only one perspective on the student's capabilities
Transition into single principles

Cognitive development is dynamic and variable. It proceeds via active construction of skills in contexts, so capabilities gradually become increasingly complex overall, despite non-synchronous developmental progress across domains.

With assumptions held in traditional psychometrics, intelligence is a stable entity within individuals regardless of contingencies affecting performance. Working with these assumptions, standardized tests miss some of the most important insights about learning, education, and cognition.

Levels of support and emotional state are important for example.
Sequence for conceptions about the relation between multiple intelligences and assessments

This theme deals with the implication of the theory of multiple intelligence (MI) on the nature and worth of traditional assessments, in particular, criticisms of the SAT from the perspective of MI theory. Conceptions range from simple statements regarding the fact that the SAT taps only one or two of seven or more intelligences, to more complex specification of the methodological limitations of psycho-metrics, the need for large scale assessments, and the cognitive and neurological bases for assuming the existence of multiple intelligences.

**Table 8: Conceptions of the relation between multiple intelligences and assessments by complexity phase**

<table>
<thead>
<tr>
<th>Complexity level</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transition into abstract systems</td>
<td>At this level, conceptions about the relationship between the theory of multiple intelligences (MI) and standardized tests involve the coordination of sets of abstractions. Often a set of abstractions about MI is offered, which is then related to a set of abstractions about standardized tests. One finds ideas like: <em>According to the theory of multiple intelligences every individual has a unique profile of strengths and weaknesses. For example, someone might have a strong interpersonal intelligence but a weak mathematical intelligence. Standardized tests, such as the SAT, can't accommodate this, because they value mathematical and verbal intelligences over other intelligences.</em> Typically, at this level, MI is cited to support the notion of individual differences, while the SAT is seen as being too simple and therefore insensitive individual differences.</td>
<td>Standardized tests are usually based on the idea that intelligence is fixed, when someone is born with a certain IQ, he is stuck with that IQ and specific tests can uncover his intelligence. (Gardner. HGSE lecture, 2005). In his book, Gardner suggested the idea that individuals are born with at least seven different kinds of intelligences, including but not limited to musical, kinesthetic, and naturalist intelligences (Gardner, 1983). However, standardized tests usually measure limited skills, namely verbal and mathematical. Standardized test are likely to mis-measure a child's true ability and his variety of intelligences. (34)</td>
</tr>
<tr>
<td>Unelaborated abstract systems</td>
<td>At this level, conceptions about the relation between MI and standardized tests involve the elaboration and coordination of abstractions into multivariate structures. Multiple sets of abstractions about MI are coordinated and then related to multiple sets of abstractions about standardized tests. For example, the following idea is common at this level: <em>Standardized tests only measure certain kinds of intelligence, which puts most students with learning disabilities at a disadvantage. Yet, when informed by the theory of multiple intelligences, classrooms can accommodate individual differences by teaching in diverse ways. Thus, some learning disabled students may succeed given the right school environment, despite poor performances on a test like the SAT.</em> Typically, one finds MI elaborated in terms of classroom practices that support individual differences, while standardized tests are described in terms of their various limitations. At this level, one also finds the beginnings of technical discussions of the cognitive / brain evidence for MI as well as unelaborated links to other complimentary (typically developmental) approaches.</td>
<td>The traditional classroom offers more opportunities to address multiple intelligences, linguistic intelligence and logical-mathematical intelligence, for example, than a standardized test (Gardner, 1998). The theory of Multiple Intelligences holds that children are smart in different ways, students can be more successful if their intelligences are taken into account at school (Gardner, 1998). Similarly, different subject areas, such as science and history, and the diversity of assignments they provide further engage multiple intelligences (Gardner, 1998). The score on the achievement test appears to indicate a weakness. Yet the classroom likely provides him with more occasions to approach material in different ways, accounting for multiple intelligences and allowing the student to better demonstrate his achievements and his understanding (Gardner, 1998). (14)</td>
</tr>
<tr>
<td>Complexity level</td>
<td>Description</td>
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<td>----------------------------------</td>
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<td></td>
</tr>
<tr>
<td>Elaborated abstract systems</td>
<td>At this level, conceptions about the relation between MI and standardized tests involve the construction of multivariate systems of abstractions. Reasoning entails the consistent employment of single terms built form multiple abstractions, such as de-contextualized assessment techniques and multiple representational modalities. For example, one finds conceptions like: Gardener describes an intelligence as a &quot;psychobiological potential&quot; to solve a certain class of problems and has identified at least seven such faculties. The kinds of problems that are the focus of most standardized tests are valid as test items, yet they probe a narrow subset of these intelligences. Given that some intelligences, such as musical or interpersonal, will never be assessable in terms of standardized test items, the idea that assessments should be more about demonstrating an understanding than answering a question becomes especially appealing. At this level, more details about the form of standardized tests are offered. It is often suggested that they are based on a misunderstanding of the nature of cognition and assessments. The evidenced in support of MI is consistently referenced, as are its educational implications. One finds the idea that each intelligence has a unique system of symbols and representations, which serve as points of entry for teaching. Intelligence can be defined as a one dimensional psychological entity (Hernstein &amp; Murray as cited in Gardner, 1998) rather than a spectrum with independently functioning parts (Gardner), such as linguistic, musical and others identified by Gardner. With such a single entity theory of intelligence, one would be perplexed by a student's varied performance; if they are in fact intelligent, then they should have that power in any situation. But, when considering multiple intelligences, it is likely that the student has varied intelligences, possessing a specific distribution of strengths and weaknesses, which may be taken into account as part of teaching styles and evaluations. Because the SAT does not necessarily favor all intelligences equally, instead relying on a single entity theory of intelligence, it misrepresents student capabilities. (44)</td>
<td></td>
</tr>
<tr>
<td>Transition into single principles</td>
<td>At this level, conceptions about the relations between the theory of multiple intelligences and standardized tests involve the organization of multivariate systems of abstractions. Conceptions entail unelaborated co-ordinations of abstract perspectives on intelligences and testing perspectives subsuming systems of abstractions. For example, one finds ideas like: standardized tests are aimed at assessing capabilities relevant for school performance, yet these capabilities are taken as amenable to the methods of psychometrics, and so successes and failures on test items are taken as indicative of degrees of ability. Clearly much of what allows for success at school cannot be assessed in this manner. The theory of multiple intelligences, with supporting evidence from cognitive neuroscience, has demonstrated that there are number of capabilities that would fall under the rubric of intelligence, most of which contribute to school successes, and only a handful of which can be assessed via traditional methods. This disjunction between what we know about intelligence and how we test students requires emendation. A more likely explanation for low test scores resides in the validity of standard tests to determine ability. Standardized tests seek to assess general intelligence across populations and do not gage individual accomplishment (Gardner, Lecture, The Disciplined Mind). Gardner proposes that humans have a number of relatively independent faculties rather than one intelligence or IQ (Gardner, 1998). Faculties are articulated through model languages specific to their domain; the standard test format is only one possible &quot;language&quot; for depicting understanding and may not be optimal for this student (Gardner, 1999). As Werner notes, &quot;an analysis of types of operations, rather than measurement merely in terms of accuracy often reveals the truer developmental picture&quot; (Werner, 1957, p.132). Low test scores say little about the student's actual abilities, which may be better assessed through methods where he/she can demonstrate &quot;Know how&quot; rather than &quot;Know that&quot; (Gardner, 1983).</td>
<td></td>
</tr>
<tr>
<td>Unelaborated single principles</td>
<td>[No examples]</td>
<td></td>
</tr>
</tbody>
</table>
**Figure 4: Maps of idealized conceptions of the relation between multiple intelligences and assessments by complexity phase**

Transition into abstract systems

- According to the theory of multiple intelligences, every individual has a unique profile of strengths and weaknesses.
- Standardized tests, such as the SAT, measure only certain kinds of intelligences, which puts them in a disadvantage by teaching yet when informed may succeed.
- Most students with learning disabilities at a disadvantage can't accommodate this because they privilege weak mathematical intelligence and strong interpersonal intelligence.
- Mathematical and verbal intelligences are such as standard cognitive systems.

Unelaborated abstract systems

- Standardized tests measure only certain kinds of intelligences, which puts them in a disadvantage by teaching yet when informed may succeed.
- Most students with learning disabilities at a disadvantage can't accommodate this because they privilege weak mathematical intelligence and strong interpersonal intelligence.
- Mathematical and verbal intelligences are such as standard cognitive systems.

Elaborated abstract systems

- Standardized tests measure only certain kinds of intelligences, which puts them in a disadvantage by teaching yet when informed may succeed.
- Most students with learning disabilities at a disadvantage can't accommodate this because they privilege weak mathematical intelligence and strong interpersonal intelligence.
- Mathematical and verbal intelligences are such as standard cognitive systems.
The conflict
what we do with regard to testing
what we know about intelligence
requires emendation
standardized tests
demonstrated
there are
only a handful of which can be assessed
The theory of multiple intelligences
supporting evidence from cognitive neuroscience
a number of capabilities
falling under the rubric of intelligence
only a handful of which can be assessed
most of which contribute
to school successes
via traditional standardized methods
in this manner
much of what allows for success at school
cannot be assessed
at assessing capabilities relevant for school performance
taken as indicative
taken as amenable
to methods of psychometrics
successes and failures on test items
so
these capabilities
transitions into single principles
successes and failures on test items
taken as indicative
of degrees of ability
Transitions into single principles
Sequence for conceptions about the relation between brain and cognition

This theme deals with conceptions about the relation between the brain and cognition. Typically, in this essay, these conceptions arise with regard to learning disabilities. Conceptions range from simple statements regarding certain neuroscience findings that support cognitive theories to (1) more complex specification of the underlying dynamics common across neurological and psychological development, or (2) explications of hypotheses regarding the impact of experience on brain development.
### Table 9: Conceptions of the relation between brain and cognition by complexity phase

<table>
<thead>
<tr>
<th>Complexity level</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transition into abstract systems</td>
<td>At this level, conceptions about the relation between the brain and cognition involve the coordination of sets of abstractions. Often a set of abstractions about the brain is offered, and then related to a set of abstractions about cognition. For example, one finds ideas like: <em>connections between neurons are affected by experience; therefore learning and cognitive development affect the brain.</em> Typically, the conceptions at this level involve drawing parallels between brain processes and cognitive processes, e.g. offering a non-controversial finding about the brain and correlating it with ideas about cognition.</td>
<td>Synaptic connections may also hold an answer to this puzzle. During brain development, the child's brain may have overproduced connections but failed to prune enough connections or perhaps pruned too many (Bransford, Brown, &amp; Cocking, 1999). In either case, the result would be one of inefficient mental processing. If this is the situation, gaining information for this adolescent might be more of an effortful procedure than for other, &quot;average&quot; adolescents.... He might not have had enough time or ability to simply process the material quickly enough to do well on the exam. (35)</td>
</tr>
<tr>
<td>Unelaborated abstract systems</td>
<td>At this level, conceptions about the relation between the brain and cognition involve the elaboration and coordination of abstractions into multivariate structures. Multiple sets of abstractions about the brain are coordinated and then related to multiple sets of abstractions about cognition. One also finds reasoning involving several oscillations between brain conceptions and cognition conceptions, as in: <em>not all brain development is genetically predetermined. Cognitive development is related to growth in synaptic connections, so learning plays a part in structuring the brain.</em> At this level, unspecified ideas about the effects of <em>environment, genetics, emotion, and scaffolding</em> emerge as considerations. Previously, cognition and the brain were merely related, now they begin to be related in context.</td>
<td>The way [students] process information, or Broadbent’s words, how the brain processes data (cited in Gazzaniga, Ivry &amp; Mangun, 2002), which in turn can manipulate only a certain amount of information, influences academic performance. Thinking is impacted by the limited information processed by the brain, and its flexibility to adapt to different situations (Siegler, &amp; Alibali, 2005). Consequently, information and assessments can be presented through various approaches that favor the students’ ways of learning (Gardner, 1998) and thinking. (23)</td>
</tr>
<tr>
<td>Elaborated abstract systems</td>
<td>At this level, conceptions about the relation between cognition and the brain involve the construction of multivariate systems of abstractions. Reasoning entails the consistent employment of single terms built from multiple abstractions, such as <em>atypical functional organization and experience-dependent plasticity.</em> For example, one finds conceptions like: <em>heritable neuron-based learning disabilities often result in unique cognitive profiles and non-standard developmental webs, which, if understood, can be used to structure appropriate pedagogical interventions.</em> At this level, stress is increasingly laid upon the complex (sometimes deemed un-analyzable) interactions between brain and cognition, which are often conceived as being roughly iterative or feedback based. There are also emerging discussions of common underlying processes.</td>
<td>This student began his education with certain biological traits that provided a framework for the formation of cognitive processes, and it was the role of the educators to take inventory of these structures and further develop them. Just as biology and cognitive capabilities determined what occurred in his education process, his education itself changed cognitive structures, which in turn changed the biological framework in which he operated. In analyzing this student's profile, it becomes evident that biology, cognition, and education exist as a system and continually influence each other in learning. (03)</td>
</tr>
<tr>
<td>Complexity level</td>
<td>Description</td>
<td>Example</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Transition into single principles</td>
<td>At this level, conceptions about the relations between the brain and cognition involve the organization of multivariate systems of abstractions. Conceptions entail unelaborated co-ordinations of abstract perspectives on the brain and cognition, perspectives subsuming systems of abstractions. For example, one finds ideas like: cognitive developmental processes are variable across contexts and domains, resulting in unique developmental trajectories. Such variability is also the result of subtle and not so subtle individual differences in brain structure, often best understood as inherited phenotypic traits. But while variability is the norm, certain common developmental processes can be identified and used to inform practice. At this level, perspectives on cognition and the brain beginning to be subsumed under overarching principles. One finds references to ideas about dynamics of interaction, functional self-organizations, and methodological considerations, which serve to coordinate highly abstract accounts of the brain and cognition.</td>
<td>The theory of dynamic structuralism &quot;starts from a recognition of the complexity inherent in human psychological development&quot; (Fisher and Bidell, 2005, p.4). Because of this tolerance for complexity, dynamic structuralism allows one to analyze the seemingly disparate data of the above profile in terms of the dynamic variability of the individual learner. The documented learning disability, for example, must be seen in light of the active interplay between brain growth patterns, genetics, and the learner's experience in social/educational contexts. Dynamic structuralism thus aims to account for both genetic and environmental factors, simultaneously emphasizing the role of neural plasticity and the potential for &quot;neurophysiological strengths [which] might be used to mitigate weaknesses&quot; (Fisher, Immordino-Yang, &amp; Waber, 2005, p.8). Using neuroimaging studies, a dynamic structuralist approach to the above case would therefore attempt to uncover the nature of the learning disability through mapping patterns in brain activity to actual learning contexts&quot; (Fisher, Immordino-Yang, &amp; Waber, p.10). (11)</td>
</tr>
<tr>
<td>Unelaborated single principles</td>
<td>At this level, conceptions about the relations between the brain and cognition involve the organization and coordination of multivariate systems of abstractions. This entails building arguments out of highly abstract perspectives in light of overarching generalizations and for the sake of principled conclusions. For example, at this level, distinct and elaborate theoretical views about cognition and the brain are brought together to justify particular statements or practical recommendations, as in: Targeted educational interventions can provide experiences that affect the functional reorganization of the brain. However, these reorganizations take place within the parameters set by more general architectural constraints. So, understanding a student's neurological profile is valuable, especially if he or she has a learning disability. This knowledge is valuable because it clarifies certain biologically based limitations students may face, thus informing cognitive developmental initiatives aimed at offering developmentally appropriate interventions. Of course, this kind of useable knowledge can only be built by intimately relating theory and practice in educational contexts. As this example illustrates, students performing at this level describe explicit overarching theoretical, methodological, and philosophical frameworks that aim to subsume a variety of abstract perspectives on the brain and cognition.</td>
<td>The brain is not a stable and isolated entity, but a dynamic and flexible system that is keenly responsive to experience (Bransford, Brown, &amp; Cocking, 1999; Gazzaniga, Ivry, &amp; Mangun, 2002; Squire &amp; Kandel, 1999). Correspondingly, cognitive capacities parallel the brain's plasticity. A synergistic interaction between genetics and experience guides the ontogeny of abilities. This student's genetic predisposition to a learning disorder imposes architectural constraints on specific aspects of brain structure, but the degree to which his disorder manifests along the possible continuum of cognitive capacity to incapacity is shaped by experience (Fischer, Immordino-Yang, &amp; Waber, in press; Plomin, Defries, McClean, &amp; Rutter, 1997; Gazzaniga et al., 2002; Squire &amp; Kandel, 1999). Therefore, the cognitive constraints imposed by this student's learning disorder are restricted to particular abilities; many other domain-specific abilities develop independent of his disorder. These non-impacted strengths can compensate for deficits. For example, a student with dyslexia can exploit developed abilities in unaffected domains, such as logic, to compensate for phonological deficits when deciphering words (Shaywitz, 2003). (05)</td>
</tr>
</tbody>
</table>
Figure 5: Maps of idealized conceptions of the relation between brain and cognition by complexity phase

Transition into abstract systems

- Connections between neurons are affected by experience and therefore learning and cognitive development affect the brain.

Unelaborated abstract systems

- Not all brain development is genetically predetermined for example cognitive development is related to growth in synapic connections so learning plays a part in structuring the brain.

Elaborated abstract systems

- Heritable neuronaly-based learning disabilities often result in unique cognitive profiles and non-standard developmental webs which can be used to structure appropriate pedagogical interventions if understood.
Transition into single principles

Unelaborated single principles

Cognitive developmental processes are variability. but while the norm is variability that can be found and used across certain common developmental processes. These processes are unique developmental trajectories resulting in contexts and domains. Such variability is also the result of subtle, and not so subtle differences in brain structure. Often best understood as inherited phenotypic traits.

Targeted educational interventions can provide experiences that affect the functional reorganization of the brain. These reorganizations can only be built by intimately relating theory and practice in educational contexts. So, understanding can take place within the parameters set by more general architectural constraints. A student’s neurological profile is valuable because it clarifies biologically based limitations certain students may face. Especially if a learning disability is has this kind of useable knowledge. So, understanding has thus informing cognitive developmental initiatives aimed at offering developmentally appropriate interventions.

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### Table 10: Summary of conceptual sequences

<table>
<thead>
<tr>
<th>Complexity level</th>
<th>Nature and nurture</th>
<th>Dynamic development and assessments</th>
<th>Multiple intelligences and assessment</th>
<th>Brain and cognition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transition into abstract systems</td>
<td>Nature is conceived as a set of abstractions about genetics, and nurture is conceived as a set of abstractions about environments, upbringing, or education. Students typically argue that both nature and nurture are important, despite the fact that some traits (such as learning disabilities) are more the result of one than the other. Genes are discussed almost solely in terms of inheritance. Gene-environment interaction is sometimes mentioned, but never elaborated.</td>
<td>no clear examples</td>
<td>Students often offer a set of abstractions about multiple intelligences to a set of abstractions about standardized tests. Students typically employ concepts from the theory of multiple intelligences to support the notion of individual differences. The SAT is criticized for being too simple and therefore insensitive to individual differences.</td>
<td>Students often offer a set of abstractions about the brain, and then relate them to a set of abstractions about cognition. Typically, arguments draw parallels between brain processes and cognitive processes. For example, a non-controversial finding about the brain may be correlated with ideas about cognition.</td>
</tr>
<tr>
<td>Unelaborated abstract systems</td>
<td>Multiple sets of abstractions about genetics are coordinated and then related to multiple sets of abstractions about environment, upbringing, or education. Nature and nurture begin to be seen as interdependent rather than opposing or contrasting forces. Both are needed to facilitate gene expression. Here we find the beginnings of conceptions about genetics and environment as being coordinated in light of a single process. At this level, the process is understood as interactive; conceptions oscillate between explaining heritability and explaining environmental effects on heritability.</td>
<td>Multiple sets of abstractions about cognitive development are coordinated and then related to multiple sets of abstractions about standardized tests. Typically, an idea, such as scaffolding, is explained. This is followed by a description of standardized testing practices that focus on their failure to take context into account. This contrast serves to justify the idea that standardized tests don’t give students what they need to perform well, such as scaffolding, which means that these tests tend to assess functional rather than optimal level.</td>
<td>Multiple sets of abstractions about multiple intelligences are coordinated and then related to multiple sets of abstractions about standardized tests. Typically, multiple intelligence is elaborated in terms of classroom practices that support individual differences, while standardized tests are described in terms of their various limitations. At this level, one also finds the beginnings of technical discussions of the cognitive / brain evidence for multiple intelligences as well as unelaborated links to other complimentary (typically developmental) approaches.</td>
<td>Multiple sets of abstractions about the brain are coordinated and then related to multiple sets of abstractions about cognition. One also finds reasoning involving several oscillations between brain conceptions and cognition conceptions. Unspecified ideas about the effects of environment, genetics, emotion, and scaffolding emerge as considerations. Previously, cognition and the brain were merely related, now they begin to be related in context.</td>
</tr>
<tr>
<td>Complexity level</td>
<td>Nature and nurture</td>
<td>Dynamic development and assessments</td>
<td>Multiple intelligences and assessment</td>
<td>Brain and cognition</td>
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<td>--------------------------------------</td>
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<td>------------------------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Elaborated abstract systems</td>
<td>Students increasingly employ single terms built form multiple abstractions, such as <em>experience-dependent gene expression</em> and enriched educational environment. The gene and environment interaction is consistently portrayed as the environmentally contingent processes of gene expression. This idea organizes well-differentiated accounts of human development.</td>
<td>Students increasingly employ single terms built from multiple abstractions, such as <em>de-contextualized assessment techniques</em> and developmentally appropriate <em>curriculum</em>. Conceptions of cognitive development connect several central ideas like <em>zone of proximal development, skill webs, or optimal versus functional performance</em>. Some general discussions of cognitive structures and processes are observed. Standardized tests are labeled as unsupportive, contrived, and insensitive testing environments. Students may argue that these tests reflect a misunderstanding of cognitive developmental processes.</td>
<td>Students consistently employ single terms built form multiple abstractions, such as <em>de-contextualized assessment techniques</em> and multiple <em>representational modalities</em>. It is often suggested that standardized tests are based on a misunderstanding of the nature of cognition. The evidence in support of multiple intelligences is consistently referenced, as are its educational implications. Students may express the idea that each intelligence has a unique system of symbols and representations, which can serve as points of entry for teaching.</td>
<td>Students consistently employ single terms built from multiple abstractions, such as <em>atypical functional organization</em> and <em>experience-dependent plasticity</em>. Stress is increasingly laid upon the complex (sometimes deemed un-analyzable) interactions between brain and cognition, which are often conceived as being roughly iterative or feedback based. There are also emerging discussions of common underlying processes.</td>
</tr>
<tr>
<td>Transition into single principles</td>
<td>Arguments are unelaborated co-ordinations of abstract perspectives on genetics and environmental factors affecting gene expression. These perspectives subsume systems of abstractions. Overarching views about how the gene/environment interaction should be understood begin to emerge. A variety of concepts are used to explicate the processes involved. These ideas are usually co-ordinations of concepts from human development, neuroscience, and education. The resulting perspective begins to specify the role of genetics in the practice of education and in understanding human development.</td>
<td>Arguments entail unelaborated co-ordinations of abstract perspectives on cognitive development and testing—perspectives subsuming systems of abstractions. Descriptions of cognitive development tend towards theoretical generalizations integrating a variety of propositions or ideas. Likewise, standardized tests are critiqued in terms of their form and underling theoretical assumptions. Broad generalizations about cognitive development and testing may structure recommendations about role of assessments in education and what testing ought to be.</td>
<td>Arguments entail unelaborated co-ordinations of abstract perspectives on intelligences and testing, perspectives subsuming systems of abstractions. Broad generalizations about the nature of human learning and intelligence are drawn from the theory of multiple intelligences. These broad views on the nature of cognition also subsume sets of concepts regarding cognitive development. Standardized tests are critiqued in terms of the limitations that arise both as a result of their form and the goals that motivate their use. These ideas result in more general recommendations about the role of assessments in education and what testing ought to be.</td>
<td>Arguments entail unelaborated co-ordinations of abstract perspectives on the brain and cognition—perspectives subsuming systems of abstractions. Perspectives on cognition and the brain may be subsumed under overarching principles. One finds references to ideas about <em>dynamics of interaction, functional self-organizations,</em> and <em>methodological considerations</em>, which serve to coordinate highly abstract accounts of the brain and cognition.</td>
</tr>
<tr>
<td>Complexity level</td>
<td>Nature and nurture</td>
<td>Dynamic development and assessments</td>
<td>Multiple intelligences and assessment</td>
<td>Brain and cognition</td>
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<td>--------------------------------------</td>
<td>-------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Unelaborated single principles</td>
<td>no clear examples</td>
<td>no clear examples</td>
<td>no clear examples</td>
<td>Students build arguments out of highly abstract perspectives in light of overarching generalizations and for the sake of principled conclusions. For example, at this level, distinct and elaborate theoretical views about cognition and the brain are brought together to justify particular statements or practical recommendations. Students describe explicit overarching theoretical, methodological, or philosophical frameworks that aim to subsume a variety of abstract perspectives on the brain and cognition.</td>
</tr>
<tr>
<td>Arguments coordinate systems of abstractions</td>
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<td></td>
<td></td>
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</tbody>
</table>
**Major themes in essay 2**

Essay 2 was far more heterogeneous than essay 1. Therefore, fewer general themes could be extracted. Only those listed below were identified and neither yielded detailed sequences.

**Neural-networks/learning**

This theme deals with the relation between neural-network models and human learning processes. In this essay discussion revolved around how rules come to be extracted from examples. Conceptions ranged from simple ideas about the similarities and dissimilarities between neural-networks and human learning to more complex specifications about how neural-networks function, methodological concerns about computer based modeling, and detailed accounts of various forms of human learning.

**Constructivist/traditional pedagogy**

This theme deals with contrasts between traditional pedagogy and constructivist pedagogy. In this essay discussions revolved around contrasts between hands-on, example based curricula, and lecture based curricula. Conceptions ranged from simple statements that both can be good to more complex explications of (1) the benefits of both relative to context, and (2) the justification of both relative to theories of cognitive development.
Conceptual change

There were few examples of reasoning at time 2 that were thematically similar to those at time 1. We found 4 examples of discussions on common themes—scaffolding and multiple intelligences (Table 11). Two of the students showed progression from the transition into abstract systems to highly elaborated abstract systems. Two showed progression from unelaborated abstract systems to highly elaborated abstract systems. These complexity scores were based on the entire essay written at each test time. The examples do not reflect the overall complexity level of the essays.

To illustrate the structure of the arguments from times 1 and 2 more clearly, we also present them as concept maps. It is immediately apparent from these maps—shown in Figures 6 through 9—that conceptual elaboration has taken place during the semester. All 4 students move from making arguments that show little depth of understanding to arguments that are more nuanced and complex. The arguments written at time 2 are more likely than those written at time 1 to incorporate multiple sources of evidence, examples, and bi-directional connections between ideas.
### Table 11: Examples of reasoning about scaffolding and multiple intelligences in the first and last essays

<table>
<thead>
<tr>
<th>CaseID Number</th>
<th>Complexity Level (pre / post)</th>
<th>Theme</th>
<th>First essay</th>
<th>Last essay</th>
</tr>
</thead>
<tbody>
<tr>
<td>24015</td>
<td>Transition into abstract systems/ highly elaborated abstract systems</td>
<td>Scaffolding</td>
<td>In contrast to SAT testing conditions, schools supply adults and peers who can raise a child's skill level. Kurt Fischer's Dynamic Skill Theory suggests that with the right kind of support or even scaffolding, children can go from a functional skill level when working alone to an optimal skill level. (Fischer &amp; Bidell, 2005). This profiled child may only be able to perform well with the right supports. He may be able to achieve more in activities such as experiments, computers, art, group projects, etc. Maybe he can only understand information when it is presented orally and/or pictorially.</td>
<td>On a psychological level, Vygotsky (1978) theorized that the mind is socially constructed through human interaction and play. For example, children who imitate others can exceed their own developmental limits and perform at higher levels. This is because their intellect can develop further with the aid of a more experienced person who can scaffold their knowledge and abilities to a higher level. Vygotsky (1978) labeled this phenomenon the zone of proximal development, which is the potential level that children can reach depending on how much support they receive. By watching others and fusing ideas, children can increase their skillfulness and learn optimally. This idea is also supported by Fischer and Bidell (2005), who claim that children need knowledgeable people who can explain concepts to them and who can provide prototypes of solutions for them to watch and imitate. These scaffolding adults are providing the structure that, as Spitzer mentioned briefly, is vital for learning.</td>
</tr>
<tr>
<td>24027</td>
<td>Transition into abstract systems/ highly elaborated abstract systems</td>
<td>Multiple intelligences</td>
<td>In addition, Gardner (1983, 1998, 1999) in his theory of multiple intelligences stated that each individual possesses abilities to solve problems and perform tasks in other capacities such as bodily-kinesthetic and musical. Thus, much of a student's capacities is unchecked by a test like the SAT.</td>
<td>Last, the theory of multiple intelligences posits that each child's mind is different and therefore each of them approaches learning differently (Gardner, 1983). In addition, Gardner (1999) proposes an &quot;individually configured education—an education that takes individual differences seriously and, insofar as possible, crafts practices that serve different kinds of minds equally well&quot; (p.151). Thus, it is important that we approach teaching in manners that befit children's learning styles. For example, adopting interdisciplinary approaches to teach mathematics through musical or even kinesthetic ways may help some children learn better. This serves to provide greater and multiple accesses to learning, and also motivates them.</td>
</tr>
<tr>
<td>24013</td>
<td>Unelaborated abstract systems/ highly elaborated abstract systems</td>
<td>Scaffolding</td>
<td>The parent (and/or sibling) might help our student do homework by creating a bullet point lists of steps, color-coding segments of text, or creating an example of a similar problem and laying out the steps to solve it. Support through example or priming might aid the student in functioning closer to what Vygotsky might call the student's optimal level of cognitive ability. (Fischer 2005) The parent might also provide scaffolding by engaging in the actual work with the student, withdrawing as the student gains competence.</td>
<td>The idea of a guiding adult helping to shape a learning experience is also central to the work of Lev Vygotsky (1978). He argues that &quot;[h]uman learning presupposes a specific social nature and a process by which children grow into the intellectual life of those around them&quot; (p. 88). This social nature draws children to work alongside adults, learning from watching and doing. …., Vygotsky would point out that the child's ability to use this example and share toys well may fluctuate according to the availability of examples. Finally, examples of a particular behavior or concept will not lead a child to deduce any understandings if the child is not developmentally ready for them. Understanding this &quot;zone of proximal development&quot; points to both potential for example-based learning, and also its limitations.</td>
</tr>
<tr>
<td>CaseID Number</td>
<td>Complexity Level (pre / post)</td>
<td>Theme</td>
<td>First essay</td>
<td>Last essay</td>
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<td>---------------</td>
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<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>24014</td>
<td>Unelaborated abstract systems/ highly elaborated abstract systems</td>
<td>Scaffolding</td>
<td>It is also important to note that the achievement test represents a low support condition, the student is working independently on a standardized test that he may not be well prepared for based on his particular school’s curriculum. Consequently, the student is working at his functional level; the greatest level of performance that he is able to sustain without support (Fischer &amp; Bidell, 2005, in press). In contrast to the level of support provided by the test is that provided within a school setting. Having earned an A average, the student has demonstrated an impressive level of success in the presumably high support environment provided by his school. Assuming that he is in a traditional classroom setting, the structure and support provided within it have seemingly allowed the student to function at his optimal level, the highest level of performance possible in a high support environment (Fischer &amp; Bidell, 2005, in press). The levels of support in a classroom versus in an achievement test are quite distinct, perhaps due to these contrasting levels of support, the compared performances are also dissimilar.</td>
<td>According to the theory of dynamic development, under low support condition one performs at one's functional level—the highest level one can achieve without support—or one can perform at the optimal level, which is the highest possible level of performance under high support conditions (Fischer et al., 2002; Fischer &amp; Bidell, 2005 in press). Support can take various forms, including direct group or individual instruction—with the oral direction and guidance of a competent expert, a child will perform at a higher level than he or she would alone (Fischer et al., 2002; Fischer &amp; Bidell, 2005 in press). As a child has opportunities to practice as an apprentice and an individual, his or her functional level will rise and approach what was once the optimal level, which will in turn rise as well (Fischer et al., 2002; Fischer &amp; Bidell, 2005 in press). This increasing skill level is demonstrative of learning that is taking place as students gain competence in environments that offer support as well as opportunities to practice. The process of learning to read provides an example of this increase in skill. A child with normal language development still requires the support provided by direct instruction in order to learn to read, while the experience of being read to provides a valuable example. Children need direct instruction to develop the decoding skills necessary for successful reading (Gough, 1972; Juel, 1991). Adults must provide additional support by explaining the connection between graphemes and phonemes as well as how to sound out words in order to help increase the child's skill level over time (Juel, 1991).</td>
</tr>
</tbody>
</table>
Figure 6: Maps of conceptions of scaffolding in the first and last essays of student 24015

First essay 24015
transition into abstract systems

Dynamic Skill Theory

suggests

children

when working alone

functional skill level

with the right kind of support or scaffolding

an optimal skill level

[the child in question] may only be able to perform with high level of support

Last essay 24015
highly elaborated abstract systems

Vygotsky (1978) theorized

the mind is socially constructed through human interaction

For example

children who imitate others

can exceed their own developmental limits

because they can perform at higher levels

because their intellect can develop

with the aid of a more experienced person

who scaffolds their knowledge and abilities to a higher level

called the zone of proximal development

idea is also supported

Fischer claims

children need knowledgeable people who can explain concepts to them

provide prototypes of solutions for them to watch and imitate.

the potential level that children can reach depending on how much support they receive

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Gardner (1983, 1998, 1999) in his theory of multiple intelligences stated each individual possesses abilities to solve problems and to perform tasks in other [a variety of] capacities. Thus, much of a student's capacities is unchecked by a test like the SAT.

In addition, Gardner (1999) proposes an education that takes individual differences seriously and, insofar as possible, crafts practices that serve different kinds of minds equally well.

Thus, it is important that we approach teaching in manners that best children's learning styles.

Adopting interdisciplinary approaches to teach mathematics through musical and kinesthetic ways may help some children learn better and also motivates them. Providing greater and multiple accesses to learning helps.

First essay 24027 transition into abstract systems

24027

Musical

Bodily-kinesthetic

Last essay 24027 highly elaborated abstract systems

Theory of multiple intelligences posts

Each child's mind is different therefore each of them approaches learning differently.

Thus, it is important that we approach teaching in manners that best children's learning styles.

Adopting interdisciplinary approaches to teach mathematics through musical and kinesthetic ways may help some children learn better and also motivates them. Providing greater and multiple accesses to learning helps.
Figure 8: Maps of conceptions of scaffolding in the first and last essays of student 24013

**First essay 24013**
unelaborated abstract systems

- help our student do homework
- support
- scaffolding
- aid the student in
- engaging in the actual work with the student
- withdrawing as the student gains competence
- functioning closer to what might call the student's optimal level of cognitive ability

**Last essay 24013**
highly elaborated abstract systems

- The idea of a guiding adult helping to shape a learning experience
- central to the work of Lev Vygotsky
- "[h]uman learning presupposes a specific social nature and a process by which children grow into the intellectual life of those around them"
- This social nature
- draws children to work alongside adults
- understanding this "zone of proximal development"
- potential for example-based learning
- limitations of example-based learning
- child's ability
- examples of a particular behavior or concept
- may fluctuate according to the availability of examples
- if the child is not developmentally ready for them
- will not lead a child to deduce any understandings
- learning from watching and doing
- points to both
- points out
- argues

Creating a bullet point lists of steps
Color-coding segments of text
Creating an example of a similar problem and laying out the steps to solve it

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Figure 9: Maps of conceptions of scaffolding in the first and last essays of student 24014

First essay
24014
unelaborated abstract
systems

- the achievement test represents a low support condition
- the student is working at his functional level
- the greatest level of performance that he is able to sustain without support
- perhaps due to these contrasting levels of support
- the compared performances are also dissimilar

High support environment provided by his school
- in contrast
- allowed the student to function at his optimal level
- the highest level of performance possible in a high support environment

Last essay
24014
highly elaborated abstract
systems

- the theory of dynamic development
- under high support conditions
- one can perform at the optimal level
- the highest possible level of performance
- support can take various forms
- one performs at one's functional level
- including direct group or individual instruction
- with the oral direction and guidance of a competent expert
- a child will perform at a higher level than he or she would alone
- as a child has opportunities to practice as an apprentice

In the process of learning to read
- this increasing skill level
- the experience of being read to provides a valuable example
- A child with normal language development
- still requires the support of direct instruction
- to develop the decoding skills necessary for successful reading
- explaining the connection between graphemes and phonemes
- in environments that offer support opportunities to practice
- this will in turn rise as well
- which will once the optimal level
- approach what was
- his or her functional level will rise

Support can take various forms
- under low support condition
- one performs at one's functional level
- the highest level one can achieve without support
- as a child has opportunities to practice as an apprentice
- this increasing skill level
- the experience of being read to provides a valuable example
- A child with normal language development
- still requires the support of direct instruction
- to develop the decoding skills necessary for successful reading
- explaining the connection between graphemes and phonemes
- in environments that offer support opportunities to practice
- this will in turn rise as well
- which will once the optimal level
- approach what was
Discussion

This project was guided by two primary objectives. We were asked to:

- assess and describe the developmental progress made by students in Mind, Brain, and Education;
- describe the relation between students’ cognitive developmental level of performance and their understanding of interdisciplinarity in Mind, Brain, and Education.

We have made some progress toward the first of these goals and considerable progress toward the second.

It is clear from our analysis that students’ attempts to integrate mind, brain, and education change with development. Arguments and their elements were overly simplified and shallow before the elaborated abstract systems level, when students began to demonstrate an adequately nuanced understanding of some of the important ideas underlying these perspectives. Interestingly, at the elaborated abstract systems level we also begin to see students “summarizing” abstract systems into single words or phrases. Not only does this summarizing (a form of integration) demonstrate a deepening understanding of the relations between the conceptual elements of a system, it makes it possible for students to begin relating systems to one another by reducing the number of individual elements that must be coordinated. These relations between systems take the form of systems subsuming systems at the transition to single principles, then finally, at unelaborated single principles, they take the form of co-ordinations between systems.

The map sequences presented in Figures 2 through 5 show how concepts build upon one another to form increasingly differentiated and integrated perspectives on each of the nature/nurture, development/assessment, multiple intelligences/development, and brain/cognition themes. A more in-depth, detailed content analysis, combined with good longitudinal evidence would reveal more detail about the way students move from one way of conceptualizing these themes to the next. However, even though we were unable to provide this depth of analysis, the sequences described in this report should be useful to educators who are interested in helping students learn to think in more interdisciplinary ways.

Future directions for MBE research

Pre and post comparisons

One of the most frustrating limitations of this project was our inability to conduct an adequate pre-post comparison. Such a comparison would contribute substantially to our understanding of developmental pathways in this domain. We suggest that in future research the pre and post assessments should be structured to encourage students to consider the same themes, facilitating more robust comparisons.

Tracing more thematic strands

The sequences presented in this report represent important thematic strands within the MBE domain. However, there are certainly more strands than the four presented here. If the study is continued, different thematic strands could be investigated and their developmental logic rationally reconstructed. Ideally all central themes could be given this treatment, resulting in a differentiated developmental overview of the domain. Such an overview would give a sense of the various demands of the domain and provide a language to understand differences between and within individuals with respect to MBE reasoning.

Studying cross-disciplinary reasoning

Many thematic strands in the MBE domain are instances of cross-disciplinary reasoning. These involve the coordination of concepts from more than one discipline. In future research, as more cross-disciplinary
strands are investigated, some generalization about the developmental logic of cross-disciplinary reasoning could be substantiated.

**The relation between developmental level and research design**

The very different notions of interdisciplinarity identified at different developmental levels, should lead to different behaviors. For example, students whose conceptions are less integrated and differentiated should have a more difficult time designing research projects that involve the integration of perspectives. On the other hand, the exercise of developing a research proposal—with adequate support—may serve to enhance students' interdisciplinary reasoning. For these reasons, we suggest that MBE students might benefit from engaging in research design.

**Scoring caveats**

The procedure of scoring essays presents the Lectical™ analyst with unique difficulties. As opposed to most spontaneous verbal performances, essays often contain explicit structures that subsume multiple arguments. These structures are often made explicit in introductory and concluding paragraphs. This complicates the normal procedure and forces a more holistic scoring strategy. Breaking the essay into sub-protocols dissolves the overall structure. It is necessary to see the levels of the sections and the degree to which they are brought into the overall piece. And yet, essays are not always what they claim to be. The explicit goal of the essay, as espoused in the introduction, is often not carried out. In cases such as these the score awarded to the essay is, in effect, more like an average of sub-protocols, because the overarching structure, while given lip service, has not actually been produced.

Overall, the kind of holistic scoring demanded in the scoring of essays results in a greater amount of within performance variability. That is, within a performance awarded a particular score, there are likely to substantive pieces of reasoning at a different level. This is unavoidable in holistic scoring because the performance is not broken up into sub-protocols.

Essays also tend to be more abstract and complex in general. Optimal performances are more likely, as are instances in which higher-level constructions are used with inadequate justification or unpacking—in effect, parroting. So, the kind of inferences we draw from them about student learning need to be circumscribed. The question of what is a more accurate representation of the state of a student's understanding, a spontaneous verbal construction, or a crafted essay, is an important one.


Dawson-Tunik, T. L., & Stein, Z. (manuscript submitted for publication). "It has bounciness inside!" Developing conceptions of energy.
