Students' Conceptions – Coherent or Fragmented? And What Difference Does It Make?*

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It is well established that students frequently answer conceptual questions incorrectly, often in predictable ways. But what is the best way of making sense of this phenomenon? And in keeping with NARST's theme this year, what are the practical, instructional implications of different perspectives? In this theoretical paper I look at this issue and articulate a perspective that has powerful practical as well as theoretical implications.

Currently there are two perspectives that have risen to prominence in an attempt to provide an explanatory framework for this phenomenon. In the first perspective, students have coherent conceptual frameworks that are at odds with canonical conceptual frameworks (Driver & Easley, 1978; Posner, Strike, Hewson, & Gertzog, 1982; Hewson & Hewson, 1984; McCloskey, 1983; Wiser & Carey, 1983; Carey, 1985, 1999, 2000; Gopnik & Schulz, 2004; Gopnick & Wellman, 1994; Vosniadou 1994, 2002; Vosniadou, Vamvakoussi, & Skopeliti, 2008). This is currently the dominant perspective in research on conceptual change. In the second perspective, students have less coherent conceptual fragments that combine to create non-canonical ideas (diSessa, 1988, 1993, 2008; diSessa & Sherin, 1998; Smith, diSessa & Roschelle, 1993; Yates et al., 1988; Clark, 2006; Clark & Jorde, 2004; Linn, Eylon, & Davis, 2004).

While this debate has been ongoing since the 1980's, it was recently fueled by a study showing substantial coherence in students' conceptions (Ioannides & Vosniadou, 2002), and a replication study that found significantly less coherence (diSessa, Gillespie, & Esterly, 2004).

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However, while this debate is important and ongoing, I argue that the "coherence" and "pieces" positions, currently spearheaded by Vosniadou and diSessa respectively, share more than might be supposed, and that these commonalities form the beginning of a consensus that has significant instructional implications.

Vosniadou and colleagues are widely, *but inaccurately*, seen as defending a view of students' conceptions as unitary misconceptions, and diSessa and colleagues are widely, *but also inaccurately*, seen as defending a view that students' conceptions are completely incoherent. While there are certainly differences between coherence and pieces views of students' conceptions, I argue here that the views overlap significantly, and that both articulate a dynamic and multidimensional view of students' conceptions.

It is the nature of academic discourse to focus on points of disagreement. This serves the valuable function of forcing proponents of differing positions to support and refine their positions. However, while it is important to debate real differences in positions, it is also important not to let the nature of academic discourse obscure points of consensus that are instructionally relevant.

<u>*Straw-person coherence and pieces perspectives*</u>. In the science education literature, many discussions of students' conceptions continue to explicitly or implicitly characterize these conceptions as unitary entities in the mind. For example, many authors discuss "the misconception that ____," where the blank could be filled in with something like "mass is not conserved during burning," "molecules expand when heated," "a force is required to make things move," "plants eat with their roots," etc., with no consideration of any substructure of these misconceptions. While Vosniadou and colleagues are often seen as providing support for such a view in the face of challenges by pieces proponents, Vosniadou herself strongly opposes such a

characterization of her position in *agreeing* with the criticisms of Smith, diSessa, and Roschelle (1993) about the misconceptions perspective:

> "…we are not describing unitary, faulty conceptions but a complex knowledge system consisting of presuppositions, beliefs, and mental models organized in theory-like structures that provide explanation and prediction." Vosniadou et al., 2008, p. 22.

So we see that Vosniadou espouses not a unitary misconceptions perspective, but rather a view of students' conceptions arising out of a complex system of knowledge elements.

By contrast, the pieces perspective is often inaccurately perceived as espousing the exact opposite of a unitary misconceptions perspective – students' naïve thought as consisting of completely incoherent knowledge fragments (called phenomenological primitives or "p-prims"). However, some of the pieces, such as Ohm's p-prim (more effort begets more effect, more resistance begets less effect) apply widely and provide a kind of organizing function, such that in similar circumstances similar knowledge elements are likely to be instantiated.

> "'Fragile' and 'random' are prejudiced descriptors that do not capture much of my view of knowledge in pieces. Elements of intuitive knowledge are contextual in that there are many of them, and they each have quite specific contextual boundaries. The region of applicability of an element might, however, be quite broad. For example, the idea that 'increased effort' begets 'greater results' applies across the physics/psychology boundary, which professional physical ideas like 'force' do not cross." diSessa, 2008, p. 44.

While diSessa would balk at calling the instantiation of something like Ohm's p-prim along with other related and relevant p-prims a "theory-like structure," it is far from the "fragile" and "random" instantiation of unrelated knowledge fragments, and it possesses a kind of dynamic structure that in certain contexts would be surprisingly robust.

So we can see that neither Vosniadou nor diSessa agree with their straw-person characterizations. Instead, both view students' conceptions as arising from a complex system of knowledge elements.

> "Our proposal that the conceptual system consists of different kinds of knowledge elements (such as beliefs, presuppositions and mental models) is also consistent with diSessa's proposal that we need to focus not on single conceptions but on rich knowledge systems composed of many constituent elements." Vosniadou et al., 2008, p. 23

This leads to a more nuanced, but I would argue a still incomplete, view of coherence and pieces perspectives.

A more nuanced, but still incomplete, view. Since both Vosniadou and diSessa consider students' conceptions to arise from a complex system of knowledge elements, consider an intricate concept map with many nodes and interconnections as representing this complex system. Vosniadou's framework could be characterized as viewing the nodes and interconnections as already being there, while diSessa's framework could be characterized as viewing just the nodes (p-prims) as being there with only a few interconnections, if any. So for Vosniadou, if a particular node is activated, this activation spreads through the web of interconnections to other nodes in consistent ways. For diSessa, a particular node being activated does not necessarily influence the activation of other nodes in all contexts.

However, this more nuanced view is still somewhat off the mark. As discussed previously, there are broader knowledge elements, such as Ohm's p-prim, that would in effect tend to interconnect p-prims that might otherwise seem isolated. And Vosniadou portrays the knowledge system not as a fixed system but as dynamic and evolving:

> "This system is not static but constantly developing and evolving and influenced by students' experience and the information they receive from the culture." Vosniadou et al., 2008, p. 22.

And so, while on first glance the intricate concept map constituting the complex system of knowledge elements for a particular topic area might for coherence advocates seem fixed, Vosniadou actually portrays the interconnections as dynamic and evolving. So on the one hand we have diSessa, who initially seems to be articulating a position of isolated knowledge fragments as in fact articulating dynamic but in practice interconnected and interdependent knowledge elements. On the other hand we have Vosniadou, who initially seems to be articulating a fixed and inviolate interconnected structure of knowledge elements as also portraying the interconnections as dynamic and evolving. So both view students' conceptions as arising from dynamically interacting knowledge elements with some level of coherence (i.e., some level of consistent co-instantiation of knowledge elements in similar circumstances).

Where they disagree is on the extent of consistent co-instantiation of knowledge elements.

> "In our view (and to the extent that knowledge elements such as p-prims could be postulated to operate in our conceptual system), p-prims should become organized in knowledge structures much earlier than diSessa believes." Vosniadou et al., 2008, p. 23

But this real disagreement should not take precedence over the equally real and substantial areas of agreement. Further, these substantial areas of agreement are not widely represented in the literature. In recoiling from a pieces perspective viewed as portraying naïve knowledge as completely incoherent, researchers seeing robust patterns of student response to conceptual questions often swing to the other extreme and portray these responses as unitary misconceptions. In recoiling from a coherence perspective viewed as portraying students' conceptions as unitary misconceptions, researchers seeing evidence of contextuality in students' responses tend to emphasize this contextuality in published reports, underemphasizing observed systematicities.

Multidimensionality. While this nuanced but still incomplete view (students' conceptions arising from a complex system of knowledge elements) lacks important dynamic aspects (to be discussed below), it does point out an important area of agreement. Both Vosniadou and diSessa view students' conceptions as arising from a system of knowledge elements in which some knowledge elements are more implicit or intuitive (Vosniadou's "presuppositions" and diSessa's "p-prims") and others are more consciously employed (Vosniadou's "synthetic models" and diSessa's "configurations of pieces").

> "Knowledge in pieces can treat large-scale conceptual structure as configurations of pieces, and that is in fact an important part of the knowledge in pieces program. Empirical work of exactly this sort has been done. I claim it provides a more powerful theory of "big chunks" by understanding their properties as stemming from their constituents, and also by providing hints as to how the chunks might have been constructed." diSessa, 2008, p. 56

Strike and Posner (1992), two of the authors on one of the seminal papers launching the conceptual change research program in science education (Posner, Strike, Hewson, and Gertzog, 1982), in their revisionist take on conceptual change agree with Vosniadou and diSessa on this multidimensional view of conscious conceptions constructed out of intuitive subconceptual elements:

> "… it may be that misconceptions do not exist in any form of representation as alternative formulations to preferred conceptions. Instead, misconceptions may exist as various factors in a conceptual ecology that function to select for or prefer some representation of a misconception when the opportunity to do so exists." (p. 156-7)

Some of my own work has focused on this important aspect of students' conceptions (Brown 1993, 1995). In this framework, I articulate four dimensions of students' ideas, some consciously employed and others intuitively employed. This allows for an articulation of the substructure of students' conceptions (e.g., Leander & Brown, 1999; Cheng & Brown, in press).

An integrative view: Students' conceptions viewed as a complex dynamic system. Both Vosniadou and diSessa are again in agreement with Strike and Posner (1992), who recommend a dynamic view of students' conceptions:

> "Our view of conceptual change must therefore be more dynamic and developmental, emphasizing the shifting patterns of mutual influence between the various components of an evolving conceptual ecology." (p. 163)

diSessa discusses the view of students' conceptions as a complex dynamic system, using as an example the emergence of the V shape of geese flying as an example of the emergence of structure.

> Within the complex knowledge system perspective, thinking or 'concept use' is the phenomenological presentation of a complex system in operation. The system, itself, much less its pieces, looks nothing like its appearance. A familiar example is that birds flock in such a way as to give the appearance of having a leader. However, there is nothing like the concept of 'leader' in the simple rules that each bird follows. The fact of a leader might emerge from a rule like (anthropomorphism aside) 'all things equal, it's convivial to fly slightly behind and to the side of a colleague.'" diSessa, 2008, p. 52

As another example of emergence, consider the "structure" of a cocktail party. Almost invariably, the cocktail party will be composed of multiple small groups of individuals conversing, even though no one has told the party-goers to get into small groups. One could take many pictures over time of the cocktail party and point to this small group structure as something robust. However, this structure emerges because of the dynamic interactions of the party-goers, not because anyone has told them to get into small groups (just as no one has told geese to fly in a V shape). In a similar way, robust systematicities can emerge among the many knowledge elements that both Vosniadou and diSessa view as comprising students' naïve knowledge. Both Vosniadou and diSessa view the naïve knowledge system as dynamic in this way (Vosniadou, personal communication, 2007; diSessa, personal communication, 2007), although with some caveats, as discussed below.

A complex dynamic system (CDS) has several characteristics. Consider a comparison between a CDS and a "regular thing" with enduring, static structure, such as a rock.

1. **Non-linear** – Changes to a regular thing are proportional to influences on it. Double the net force on a rock, and its acceleration will double. With CDS's, at times strong influences can lead to little change (strong stabilities or "attractors" develop that are affected little by external influences), and at times weak influences can lead to substantial, often unpredictable changes (often called the "butterfly effect").

2. **Dynamic evolution** – Regular things tend to stay the same over time. CDS's tend to evolve over time.

3. **Emergence** – Regular things are identifiable, static structures (e.g., a rock). Left by itself it will remain what it is. A CDS is a dynamically emergent structure (e.g., a living organism). Left by itself it will "die" and decay without inputs of energy.

4. **Embeddedness or interdependence** – Remove a piece from a regular thing (e.g., cut off a piece of a rock), the piece and the whole are not changed (except by being separated from each other). It is possible to separate systems into components. Remove a piece from a CDS (e.g., remove a heart from a person), both the piece and the whole are substantially changed. The body dynamics embed the heart dynamics, and the heart dynamics are embedded in the body dynamics.

Non-linearity is at the heart of research on students' conceptions – the finding that even with significant influence through instruction, students' conceptual ideas often remain largely unchanged. This observation agrees with a central characteristic of a dynamic conceptual system, conceptual attractors that can be surprisingly robust. Both Vosniadou and diSessa clearly agree with the **evolution** of conceptual ideas over time as the evolution of the conceptual system is a central focus in both their frameworks. diSessa clearly agrees with **emergence** – any identifiable systematicities in student thought are the result of dynamic emergence from the complex system of knowledge elements. Vosniadou has recently also come to agree with this position of dynamic emergence (personal communication, April 2007). However, emergent structures can be fleeting or highly stable. Vosniadou and diSessa do still disagree about the extent of stability of the emergent dynamic structures. Finally, with regard to **embeddedness**, Vosniadou's view is based on the interdependence of various knowledge elements – presuppositions, mental models, ontological commitments, etc., and she often discusses the need for social interaction in learning. diSessa tends to focus on the subconceptual world of p-prims, but he does focus to some extent on larger configurations of p-prims in considerations of students' conceptions.

<u>*Some instructional implications of a dynamic view*</u>. So we can see that Vosniadou and diSessa, as the major proponents of the coherence and pieces views respectively, actually agree on a great deal. In particular, they agree that students' conceptions are best thought of as a multidimensional complex dynamic system. Such a view has a number of practical, instructional

implications, some of which I discuss below to illustrate the practical importance of this consensus.

1. Instruction needs to pay attention to the complex knowledge systems of students. Rather than either ignoring students' ideas (as does traditional instruction) or focusing on unitary, faulty conceptions, teachers need to pay attention to students' existing ideas as an interdependent system of intuitive and conscious ideas, some of which will be problematic, others of which will provide starting points for conceptual change and growth. This leads to the second point.

2. This interdependent system of intuitive and conscious ideas will often include ideas that can provide intuitive "anchors" (Clement, Brown, & Zietsman, 1989). Teachers can help students extend their understanding of these anchors through analogical and model-based reasoning. The underlying basis of this use of analogies and models (Brown & Clement, 1989, Brown 1993; Gutwill, Frederiksen, and White, 1999; Dagher, 1998; Gilbert & Boulter, 2000; Clement & Steinberg, 2002; Clement, 2008) is that students will have conceptual resources (Hammer, 2000) in one context that they can use in a different context. In other words, analogies and models may be understood in terms of drawing connections among different parts of the dynamic conceptual system, and these connections may give rise to new stabilities (Brown & Hammer, 2008).

3. Students' conceptual dynamics, with embedded conscious and intuitive elements, are themselves embedded in affective, social, epistemological, and sociocultural dynamics (Leander & Brown, 1999, Hammer, 1994). The importance of social interaction in constructivist learning environments has long been recognized, and a dynamic view provides

an elegant explanation for this finding – just as the body systems need to be working together for biological growth, so all the dynamics of the constructivist learning environment need to be working together for optimal conceptual growth.

4. Teachers can help their classes navigate these interdependent dynamics so that conceptual change and growth is more likely (Brown, 2000). However, because of the unpredictability of the interdependent dynamics, teachers need to be armed with flexible, research-based curricula and particularly with awarenesses of the interdependent dynamics and effective ways of navigating these dynamics. Such awarenesses are greatly strengthened through professional interactions among practitioners, and where professional interactions are encouraged and supported through such mechanisms as professional learning communities and lesson study, learning gains are evident (Lewis et al., 2006, DuFour & Eaker, 1998).

5. Unlike the unitary misconceptions view that sees conceptual change as "flipping" from the misconceived view to the correct view, a dynamic view sees conceptual change and growth as an evolution over time of the dynamic conceptual system. As mentioned above, this evolution is greatly aided through coordinated action of the interdependent dynamics (conceptual, affective, epistemological, social, sociocultural, etc.), but the evolution will take time. This means that instruction aimed at genuine conceptual change and growth will encourage the operation of these dynamics over extended periods of time rather than viewing a "constructivist lesson" as a quick fix.

6. The almost unquestioned assumption in most instruction is that if we want students to learn more, we need to teach more *at a faster uniform pace*. If we need to build a brick wall faster, we need to put the bricks on top of each other at a faster uniform pace. However, if students'

conceptions form a complex dynamic system, we might expect progress in the system to be non-linear; we might think of an analogy to population growth rather than to adding bricks in the wall. Instructionally, this would mean expecting a period of slow growth at the outset with more rapid progress later, as ideas connect to and build on the initial conceptual understandings (Brown & Hammer, 2008). Trying to speed up the necessary initial conceptual groping could prove counterproductive in the long run. Allowing for the necessary growth will at first be slow but will likely eventually outstrip linear instructional approaches.

Conclusions and importance for the NARST community. The coherence vs. pieces debate is often inappropriately seen as a debate between those viewing students' conceptions as unitary misconceptions and those viewing students' naïve thought as completely incoherent and random. With these choices, it is not hard to see why a prevalent view today is of students' naïve ideas in science as unitary misconceptions, as many robust conceptual difficulties have been identified. However, as discussed above, these are straw-person perspectives that do not accurately represent the views of leading coherence or pieces advocates. However, it is important to stress that aspects of these straw-person perspectives are still widely represented in the literature, particularly the perspective of students' conceptions as unitary misconceptions (e.g., "the misconception that _____," where the blank could be filled in with "plants eat with their roots," "matter is lost in burning," etc.). I want to emphasize that *both* Vosniadou and diSessa argue strongly against this perspective, each taking the position that it is vital to pay close attention to the substructure of these conceptions.

Having said this, the reader may be tempted to conclude that I am implying that diSessa and Vosniadou agree on everything. This is definitely not the case, and there are still many points of discussion and debate. In an attempt to be as clear as possible, I list below both what I am <u>not</u> arguing as well as what I <u>am</u> arguing.

What am I **<u>NOT</u>** arguing:

- That diSessa and Vosniadou are saying pretty much the same thing. This is definitely not the case, and there are still significant disagreements.
- That diSessa agrees with a unitary misconceptions perspective. <u>Absolutely not</u> – both Vosniadou and diSessa strongly disagree with this position.
- That diSessa agrees with a framework theory perspective. He does not. While he views p-prims as co-instantiated in particular contexts as configurations of pieces, he argues that often with slight contextual changes the co-instantiation no longer occurs.
- That Vosniadou agrees with a pieces perspective. She does not. She maintains that students' subconceptual ideas are organized into implicit theoretical frameworks – framework theories that are much more widely applicable than diSessa's more contextual configurations of pieces.
- That Vosniadou and diSessa agree on all instructional implications. While there is overlap on some instructional implications (as discussed earlier), they still have significant disagreements on some specific implications, such as the importance of focusing on students' "naïve theories" in instruction.

What I AM arguing:

- That both diSessa's and Vosniadou's views are often caricatured incorrectly and are widely misunderstood.

- That when looked at carefully, there is some significant overlap in the perspectives of Vosniadou and diSessa.
- That this overlap leads to a multidimensional complex dynamic systems view of students' conceptions and conceptual change.
- That this complex dynamic systems view has significant instructional implications.

So while there are still points of debate between coherence and pieces advocates, there is also much consensus. Drawing on these points of consensus leads to a powerful view of students' naïve thought as a dynamic conceptual system embedded in and embedding other dynamic systems. Taking this dynamic view leads to important practical implications, and, as argued in Brown & Hammer (2008), to important areas for future research. As a community we need to continue to debate areas of non-consensus. But we also need to move forward in areas of consensus, drawing on powerful theoretical frameworks for the advancement of both research and practice.

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