CHAPTER 4: CLASSIFYING STUDENTS' SENSE-MAKING STATEMENTS

Overview

The purpose of this chapter is to provide an answer to the first research question of this study:

How can we classify students' sense-making statements?

I started with Giyoo Hatano's *comprehension activity* (CA) as my initial theoretical framework for how students' verbal sense-making discussions might proceed. However, after careful analysis of the small-group discussion in this study, I discovered that Hatano's framework needed to be modified before it could accurately reflect the sense-making statements in these discussions. Specifically, Hatano's initial four components of nonverbal sense-making were expanded and elaborated into six components of sense-making discussion.

Hatano's four initial components of nonverbal sense-making were:

- Seeking of new information
- Generation of inferences
- Searching for knowledge compatibility
- Retrieval of prior knowledge

My own six components of sense-making discussion, which evolved from Hatano's four original components, ultimately took the following form:

- Predicting a phenomenon or experimental outcome
- Clarifying the facts of a phenomenon or experimental result
- Describing and explaining a phenomenon or experimental result

- Defining, describing, clarifying, and connecting scientific concepts, procedures, processes, and representations
- Testing knowledge compatibility
- Making a request for any of the above

The Six Components of Sense-Making Discussion

Because my six components of sense-making discussion (SMD) are quite a bit different from Hatano's four original components of nonverbal sense-making (i.e., comprehension activity), I'll briefly summarize how my six-component framework for SMD came into being.

The Evolution of my Framework for Sense-Making Discussion

As outlined in Chapter 2, Hatano's comprehension activity (Hatano, 1987) has four components: seeking of new information, generation of inferences, searching for knowledge compatibility, and retrieval of prior knowledge. It was these components that eventually evolved into the six components of scientific sense-making discussion listed above.

This evolution proved to be necessary for four reasons: 1) my own view on the nature and purpose of sense-making differed from Hatano's, 2) some of Hatano's original sense-making components overlapped with or subsumed one or more of the other components, 3) some of Hatano's original components reflected a level of analysis that was too microscopic a level compared to the level of sense-making discussion that I ultimately found most interesting and relevant, and 4) my final version of the components of sense-making needed to reflect the study's verbal (rather than nonverbal) focus. This evolution occurred over many months during my initial analyses of the students' small-group scientific discourse.

The first major modification was to change my sense-making focus from "generating scientific explanations" (the purpose of comprehension activity, according to Hatano) to "generating new understanding". That is, I came to realize that the generation of an explanation was not always the endpoint of sense-making activity; instead, it could be seen as one particular component of the more general process of constructing a new understanding. The resultant effect on the four original components of sense-making was that "generation of inferences" was expanded to become "generation of inferences and explanations".

Next, I realized that further development of the components was necessary because certain components of sense-making (searching for knowledge compatibility, generating an explanation) were actually macro-level processes that could be broken down into one or more of the other components/processes (inference-generation, knowledge-retrieval). For instance, when a student says "we know that forces cause objects to speed up, and so I'm guessing that they also cause objects to slow down", she has engaged in the process of generating an explanation of the concept of "force". Yet, this general "explanation-building" process clearly consists of a retrieval of prior knowledge (forces cause objects to speed up) and the generation of a new inference (forces also cause objects to slow down). Therefore, because I had discovered that the four components of sense-making actually represented two different levels of categorization, it became necessary to separate the components of sense-making into the two levels: macro-level processes and micro-level processes. My initial set of macro-level processes consisted of the generation of explanations, the search for knowledge compatibility, and the search for new information. The micro-level processes consisted of the generation of inferences and the retrieval of prior knowledge.

However, upon separating the components into macro- and micro-level processes, I realized that the macro-level sense-making processes were most interesting and relevant in the context of this study. Therefore, I abandoned the micro-level processes and set a new goal of identifying the other types of macro-level verbal sense-making in which the students became engaged. Eventually, I was able to more fully describe students' verbal sense-making by splitting "explaining" into two separate components -- 1) describing/defining/connecting scientific concepts, processes, procedures, and representations, and 2) describing and explaining a phenomena or experimental result -- and adding two new components: predicting a phenomenon or experimental outcome, and clarifying the facts of a phenomenon or experimental result.

Lastly, taking into account the verbal nature of my sense-making data, it became clear that Hatano's "searching for new information" component manifested itself during scientific discussions as requests for fellow group members to engage in the other five components of SMD. During small-group discussions, "searches for new information" consisted of requests for predictions, clarifications, explanations (both types), and/or tests of knowledge compatibility. The "search for new information" component was renamed to reflect this fact.

A depiction of the evolution of my six components of sense-making discussion can be found in Figure 4-1.

Change in Focus

Generation of Scientific Explanations → Generating New Scientific Understandings

Modification to Framework	Evolution of Components				Reason for Modification
Hatano's 4 original components of comprehension activity	Seeking new information	Generation of inferences	Retrieval of prior knowledge	Testing knowledge compatibility	
Incorporating explanations into inference category	Seeking new information	Generation of inferences and explanations	Retrieval of prior knowledge	Testing knowledge compatibility	Change in focus
Splitting into micro- and macro-level components	Seeking new information	Generation of explanations		Testing knowledge compatibility	Generation of explanations consists of generating inferences and retrieving prior knowledge
Micro-level components discarded	Seeking new information	Generation of explanations		Testing knowledge compatibility	Micro-level components less interesting
Generation of explanations spilt into two components	Seeking new information	Explaining a concept, process, or procedure	Explaining a phenomenon or result	Testing knowledge compatibility	Explanations of ideas and phenomena qualitatively different
New macro-level components added	Seeking new information	Explaining a concept, process, or procedure Predicting a phenomenon or result	Explaining a phenomenon or result Clarifying the facts of a phenomenon or result	Testing knowledge compatibility	Two other components seen as relevant to process of generating new understanding
"Seeking new information" component renamed	Making a request for sense-making	Explaining a concept, process, or procedure Predicting a phenomenon or result	Explaining a phenomenon or result Clarifying the facts of a phenomenon or result	Testing knowledge compatibility	Change made to reflect verbal nature of sense-making discussion

Figure 4-1: Evolution of the Six Components of Sense-Making Discussion from Hatano's Four-Component Framework for Comprehension Activity

Descriptions and Examples of the Six Components of Sense-Making Discussion

Predicting a phenomenon or experimental outcome. An instance of predicting contains a predicted phenomenon or experimental outcome (that which is being predicted), and may also include supportive reasoning. Verbally, predictions implicitly or explicitly take the form of:

(predicted phenomenon or outcome) because (optional reasoning: inference or retrieved knowledge)

To distinguish between guess-like predictions and predictions that have been given more thought, predictions are broken down into two levels: Level 1 and Level 2. A Level 2 prediction includes supportive reasoning. A Level 1 prediction does not.

Supportive reasoning might consist of concepts, procedures, representations, mathematical operations, or concrete examples.

Examples of Level 1 predictions:

In activity 2 of cycle 3 (Lots of Pulls!), Lacey (group 1) made a prediction about the motion of a pulley with two aliens hanging on one side (Stas, Kinet) and one alien hanging on the other side (Teract). The "aliens" were made out of lego blocks; Stas' body was made of three legos, Kinet's body was made of four legos, and Teract's body was made of seven legos. Therefore, each side had a total of 7 legos pulling on the pulley system. Lacey's prediction: "This is going to be even, I bet." Since Lacey didn't provide any supportive reasoning for her prediction (that the pulley system wouldn't move), this was classified as a level 1 prediction.

Another example of a level 1 prediction is from activity 1 in cycle 4 (Will it Slow Down?), in which students were asked to consider whether a pushed skateboard (on earth), bicycle (on earth), shopping cart (on earth), and wrench (in space) would keep moving at a constant speed or eventually slow down. Arthur predicted that the skateboard, bicycle, and cart would slow down, and that the wrench would not slow down. His exact words were: "The first three are 'no', the last one is 'yes'. I assume." This is a level 1 prediction because Arthur did not provide reasoning for his prediction, just as Lacey did not provide reasoning for the lego/pulley prediction above.

Examples of Level 2 predictions:

During activity 1 of cycle 3 (Can You Lend Me a Hand?), Lacey offered a prediction about an imagined tug-of-war. The question on the worksheet read: "What does your team think? Will it help Kinet's side if several of the aliens pull together against Teract, even though Teract is stronger than the others? What is your reasoning?" (Activity 2, with the legos, was a development activity that built on the elicitation of students' initial ideas in this activity.) In thinking about the worksheet question, Lacey made the following statements:

L They would -- Stas and Kinet -- would have an equal chance of beating Teract, and Teract would have an equal chance of beating them.

D Yeah. That's what I put, basically.

L Because if their weights add up to... or if their strengths add up to the same amount of strength that Teract has, then they have a fair chance of beating Teract...because it's two against one, but it'd be a fair game because it's strength, not how many people they are

The instance of verbal sense-making starts with "They would -- Stas and Kinet --- would have…" and ends with "…how many people they are". This was counted as a level 2 prediction because Lacey provided supportive reasoning (total pull based on strength, not how many people) for the predicted phenomenon (the aliens having an equal chance of beating each other in the tug-of-war).

Another example of a level 2 prediction came only seconds after Arthur's level 1 prediction concerning the skateboard, shopping cart, bicycle, and wrench. The level 2 prediction was prompted by Sabrina's request for evidence, as follows:

A The first three are "no", the last one is "yes". I shall assume.

R I shall assume.

S (to A) So the first three are "no"?

A Mmm hmmm. Because, see, a skateboard will always slow down because of the friction on the wheels.

In this example, Arthur's initial level 1 prediction prompted Sabrina to ask for Arthur's reasoning behind his prediction, with the result that Arthur re-stated his predicton ("Mmm hmmm"), and then backed up his prediction with evidence: "a skateboard will always slow down because of the friction on the wheels".

Arthur's restated prediction was supported by evidence, and so the restated prediction was classified as a level 2 prediction.

Clarifying the facts of a phenomenon or experimental result. This component involves those instances of SMD where students clarify the facts of a phenomenon or experimental result as they remember or reconstruct the phenomenon/result. Generally, the purpose of the clarification is to ensure that the group members understand the basic details of the phenomenon/result.

Examples from student conversation:

In activity 3 of cycle 4 (Slowing Down), Lacey and Darla watched a wooden block speed up (as they applied a force), slow down (after they removed the applied force), and then stop. They then had the following conversation:

L So, [didn't the block] speed up and slow down?

D Yeah, but [the block didn't] speed up very much.

In this case, because of the focus on the details of a phenomenon, Darla's statement was categorized as a clarification of a phenomenon (i.e., a clarification of the motion of the block).

In activity 2 of cycle 5 (Exploring What Causes Gravity), Sabrina and Arthur made clarifying statements about gravity as they jointly reflected on the phenomenon of gravity in space. Their conversation:

S What's holding the earth up?

A I figure the gravity of the sun...is holding it up in place.

S There's no gravity in the atmosphere.

A Oh yes, the sun has very strong gravity.

Sabrina began the conversation with a request for an underlying explanation ("What's holding the earth up?'), in response to which Arthur provided an explanation for what holds up the earth: "the gravity of the sun". The first clarification in this exchange was Sabrina's response to Arthur's explanation: "there's no gravity in the atmosphere". Her response is a clarification because Sabrina was attempting to clarify the basic details of whether gravity actually exists in earth's atmosphere. Next, Arthur responded with a clarification of his own, as he argued that "the sun has very strong gravity". Arthur's statement was a clarification for the same reason that Sabrina's was a clarification -- in arguing that yes, the sun does have gravity, he was clarifying the basic facts of a physical phenomenon.

Describing and explaining a phenomenon or experimental result. This component of SMD involves describing physical phenomena or experimental results in new terms (in terms of scientific concepts or micro-level phenomena, for example) and determining the underlying explanation for phenomena or experimental results.

For example, when a student re-describes the motion of a thrown baseball (on Earth) in terms of initial velocity, movement through air, and horizontal/vertical accelerations, he or she has described the phenomenon in new terms. If the student goes one step further and describes how the force of gravity and air friction change the ball's velocity over time, then the student has provided the underlying explanation for the motion of the ball.

Examples from student conversation:

In activity 3 of cycle 3 (Slowing Down), groups slid wooden blocks across their tabletops. They were then asked to provide an answer to the following question: "What causes the block to slow down as it slides along your desk?" Lacey and Darla (group 1) had a brief discussion related to this question:

L That loses…energy -- motion energy?

D It loses energy, then…wait…yeah. It probably has something to do with friction.

Here, Lacey introduced scientific terminology (loss of motion energy) to describe the block's "slowing down" motion. Darla then built on Lacey's contribution by providing an explanation for this motion: the presence of friction. Each statement (Lacey's, Darla's) was therefore counted as an instance of describing/explaining a phenomenon/result.

An example of an underlying explanation from group 2 comes from activity 4 in cycle 4 (Gravity and Motion). In that activity, groups let both crumpled and flat pieces of paper drop to the ground in order to examine and explain their motion. This activity elicited explanations from both Arthur and Sabrina, as seen here:

S (reads) "Now hold the sheet of paper and the paper ball at the same height and drop them." (S drops them) "What did you observe?"

A The ball went down faster than the paper.

S (writing) "...faster." (to A) That's what I'm writing!

S (reads) "Can you explain your observation?"

A Because the [flat, uncrumpled] paper is wider, the drag is greater. (S not really listening)

S Hold on…the [crumpled] ball is smaller, and [the flat paper] is wider...the [crumpled paper] ball is smaller, so it has less mass...

A They have the same mass.

S No, I mean...(grabs crumpled ball and flat paper)...the [air under the flat paper] is like...air pushing...drag! The [flat paper] has more drag.

The order of sense-making statements in this excerpt is the following:

- Arthur clarifies the facts of the phenomenon (the ball went down faster than the paper)
- Arthur provides an explanation for the motion of the dropped pieces of paper (because the flat, uncrumpled paper is wider, the drag on the flat piece of paper is greater)
- Sabrina clarifies the facts of the phenomenon (the crumpled ball has less mass)
- Arthur clarifies the facts of the phenomenon (the pieces of paper have the same mass)
- Sabrina provides an explanation for the motion of the dropped pieces of paper (there is more drag on the flat piece of paper)

Arthur's and Sabrina's explanations of the motion of the crumpled and flat pieces of paper are fairly representative of the many describing/explaining components of SMD found in the small-group discussions in this study.

Defining, describing, and connecting scientific concepts, procedures, processes, and representations. An instance of this component of SMD contains a subject (that which is being explained) and an idea statement, and may also include supportive reasoning. Verbally, these instances of SMD implicitly or explicitly take the following forms:

(idea statement: inference or retrieved knowledge) because (optional reasoning: inference or retrieved knowledge)

or

(optional reasoning: inference or retrieved knowledge), so (idea statement: inference or retrieved knowledge)

Idea statements are statements that:

- describe what a concept is/is not;
- describe how a process or procedure works/does not work;
- describe what a representation does/does not represent; or
- make connections between concepts, procedures, processes, and representations.

Examples:

In activity 4 of cycle 3 (Putting it All Together), Arthur made an interesting generalization while trying to help his group answer a question ("Can pushes and pulls be combined?") on the group's wipe board. Arthur's sense-making statement was the following: "Since you combine weight, that means you can combine pulls; that means you can also combine pushes." This statement was categorized as a defining/describing/connecting instance of SMD that addresses the subject of pushes/pulls. The inferred characteristic (description) in this case is that pushes and pulls can be combined, which was supported by this chain of supportive reasoning: weights can be combined, (implicitly) weight is a type of pull, and pushes are similar to pulls.

Arthur's description of pushes/pulls also serves to draw out the finer differences between this component of SMD (defining, describing, connecting a concept, procedure, process, or representation) and the component dealing with descriptions/explanations of phenomena or experimental results. The primary difference, as seen here, is that definitions or descriptions of ideas are not limited to a particular context. That is, when someone argues that "pulls can be combined", it is generally meant that all pulls can be combined, not just that a special group of pulls can be combined under certain circumstances. In contrast, descriptions or explanations of phenomena/results are the applications of these general concepts to specific phenomena, such as when Arthur and Sabrina explained that the slower speed of the flat piece of paper (the phenomenon) was due to air drag (a concept).

An example of the connecting portion of the describing, defining, and connecting component of SMD can be found in group 1's discussions from activity 2 of cycle 4 (What's a Little Friction?). In one segment of that activity, students were asked to draw force arrows that represented the frictional effects of smooth and rough table surfaces on a pushed block. When group 1 reached this activity segment, Darla and Lacey had the following conversation:

D (reads) "Explain the length of the push arrow that you drew." Because the sandpaper is rougher...

L [The rougher surface] has a stronger resistance.

D Yeah, but would [the force arrow associated with the rougher surface] be shorter or longer? Because if there's more resistance...(looks at paper)

L I think that it would be shorter if it makes more resistance.

D No, I think it's longer. (pause) Yeah, longer. Because there's more resistance on the rough [surface].

The order of sense-making statements in this excerpt is the following:

- Lacey describes the rougher surface as having more resistance
- Darla asks Lacey to explain how the resistance of the rougher surface should be reflected in the force diagram
- Lacey connects the force representation (diagram) to the concept of rougher resistance by arguing that the force arrow should be shorter for the rougher surface
- Darla connects the force representation (diagram) to the concept of rougher resistance by arguing that the force arrow should be longer for the rougher surface (here, Darla contradicts Lacey)

All but the second instance of sense-making were classified as instances of SMD dealing with describing, defining, and connecting concepts, procedures, processes, and representations. (The second instance -- Darla's question to Lacey -- was an example of a request for sense-making, which is a different component of SMD.) Lacey's first statement described the rough surface in terms of its characteristic of having a large amount of resistance, and so her statement is a partial description of a concept (roughness), and therefore an example of this component. Lacey and Darla's later statements made connections between the force provided by the rough/smooth surfaces and their representations on the force diagram, and so these statements -- in that they connect concepts to representations -- also count as instances of describing, defining, or connecting concepts, processes, procedures, or representations.

Testing knowledge compatibility. Tests for knowledge compatibility are instances of SMD where students explore the validity of scientific ideas and explanations or explore the consistency of scientific results and phenomena. In the present study, this testing of validity/consistency took a number of different forms:

(a) comparing experimental results with predictions

(b) comparing earlier experimental results with later experimental results

(c) bringing up a potential counterexample or inconsistency

(d) comparing a phenomenon to a slightly modified version of that phenomenon

(e) contrasting one phenomenon with another

(f) imbedding a scientific idea (concept, process, procedure) in a new phenomenological context

(g) comparing the underlying explanations of different physical phenomena

(h) questioning whether or not a physical phenomenon or experimental outcome is possible

Examples:

An example of (a) was Lacey's (group 1) statement in activity 1 of cycle 3 (Can You Lend Me a Hand?) that "our predictions were wrong." She made this comparison of an experimental result with a prediction after the group made a prediction, conducted an experiment, and recorded the experimental results.

An example of (c) can be found in activity 3 of cycle 5 (More Exploration of What Causes Gravity). In this activity, students were directed to two pencils side-by-side on their desks and explain why the pencils don't gravitationally attract one another. Over the course of group 1's discussion of this "experiment", Lacey agreed with Darla that a pencil and notebook should attract each other, but then Lacey eventually made the argument that two pens attached to a meter stick that is free to rotate (like in the Cavendish experiment) don't attract each other, because "there's nothing in between them that would be pulling them together -- just air". In response, Darla brought up the fact that "there's nothing in between the [pen and notebook], either". Darla's response was an example of a

(c) type of test of knowledge compatibility, because Darla was pointing out an inconsistency in Lacey's argument.

A type (d) test of knowledge compatibility can be found in group 2's discussion from activity 1 of cycle 3 (Can You Lend Me a Hand?). In answering the question " Will it help Kinet's side if several of the aliens pull together against Teract [in a tug-of-war], even though Teract is stronger than the others? What is your reasoning?", the group members had the following discussion:

A I said "just like math". Teract equals 4, Stas and Kinet each equal 2. You add the two smaller things together equals just as much as the big number.

S Why don't you do Teract equals 2 and Stas and Kinet equal 1?

A Same thing. Just smaller numbers.

Sabrina made a request for a test of knowledge compatibility when she pushed Arthur to explain why using values of 2 and 1 (as strength/force values) wasn't just as valid as using the values of 4 and 2. Arthur's response ("Same thing. Just smaller numbers.") was a type (d) test of knowledge compatibility in that it compared the use of both sets of strength values (implicity) and explained that the result of the tug-of-war would be identical for the two sets. That is, thanks to Sabrina's request, Arthur compared a phenomenon (strength values of 4 and 2 in the tug-of-war) to a slightly modified version of that phenomenon (strength values of 2 and 1).

An example of contrasting one phenomenon with another, a type (e) example of a test of knowledge compatibility, is in Darla's direct response to a question in activity 2 of cycle 4 (What's a Little Friction?). The question posed to the students was: "How does rubbing the backs of your hands together compare to rubbing the palms together?" Darla's response -- "it's different; it's on a smoother surface" -- was a prompted contrast between one phenomenon (the rubbing of palms) and another (the rubbing of backs of hands), and was therefore an example of (e).

An example of a type (g) test of knowledge compatibility is from activity 1 in cycle 4 (Will it Slow Down?), in which students were asked to consider whether a pushed skateboard (on earth), bicycle (on earth), shopping cart (on earth), and wrench (in space) would keep moving at a constant speed or eventually slow down. Arthur predicted that the skateboard, bicycle, and cart would slow down, and that the wrench would not slow down. Arthur went on to explain that: "A skateboard will always slow down because of the friction on the wheels. A bicycle is the exact same thing. And exact same with the shopping cart." This statement was classified as type (g) because Arthur equated/compared the underlying explanations for all three phenomena (friction in all three cases).

The last type of test for knowledge compatibility -- type (h), questioning whether a phenomenon/result is possible, which is the same thing as comparing a phenomenon/result to all of one's prior experience -- can be seen twice in activity 3 from cycle 4 (Slowing Down). The first instance came about when group 2 argued whether, when a person gives an object constant speed from rest, the object speeds up when the force is applied to it, or whether it instantaneously starts at its constant speed. Roxanne argued that it instantaneously starts at its constant speed, while Arthur and Sabrina argued that it must speed up. During the group's conversation, Sabrina asks Roxanne "How could [the object] start [at its constant speed]?", which was a request for a test of knowledge compatibility, since it questioned the possibility of the phenomenon. Arthur's response -- "only a machine can make that happen" -- was a type (h) test for knowledge compatibility because it explained that there was only one condition under which the phenomenon could be possible -- if a machine provided the necessary "instantaneous" force. Later that same activity, when the group discussed how a wrench might be launched into space, Roxanne suggested that someone might "[throw] it so high that it went into space", to which Sabrina replied: "Ok, like someone's going to throw it that high. That's like millions and billions of miles away." This was the second example of (h) in this activity. Sabrina's comment was so classified because she questioned whether it was actually possible for someone to throw a wrench into space from the surface of the earth.

Types (b) and (f) were recognized as other possible ways to test knowledge compatibility, although no examples of these two types were seen in the student discussions in this study.

Making a request for a prediction, clarification, explanation, or test of knowledge compatibility. This component of SMD is not very different from Hatano's nonverbal "search for additional information". The only difference is that nonverbal searches draw upon one's own prior knowledge and experience, and verbal searches draw upon the knowledge and experience of other people.

In this study, students did exactly what one would expect to draw upon the knowledge and experience of their group members: they asked them questions. In these questions, students asked their groupmates to contribute predictions, explanations, clarifications, and tests of knowledge compatibility to the discussion at hand. An important point here is that students often read questions aloud from the written curriculum, but these readings were not counted as instances of this component of SMD. This is because read statements/questions were never counted as SMD for the purposes of this study.

Examples:

Below are examples of requests for the different types of sense-making. Also listed are the activities and cycles from which these examples are drawn.

Table 4-1. Examples of requests for sense-making.

Question	Type of Request	Activity	Cycle
"Is [the block moving at] constant speed to a straight stop, or is it slowing down?"	Clarification of a phenomenon	3	4
"If spinning causes gravity, then [the lego attached to the pencil with the string] would go toward the [pencil], right?"	Prediction	2	5
"Why didn't [the pencils on the table] go next to each other?	Explanation of a phenomenon	3	5
"Do [pulls that are going in opposite directions] really combine? Because they're going against each other."	Describing a concept or process	2	3
"How could [the object] start [at its constant speed]?"	Test of knowledge compatibility	3	4

Comparing the Six Components of Sense-Making Discussion

A last comment on my six components of sense-making discussion is that some components are clearly more important than others when trying to develop an in-depth, robust understanding of a new scientific idea. Clarifications of facts are minor clarifications of detail, for instance, and so the "clarifying the facts of a phenomenon or result" component of SMD could probably be categorized as the component that is least important (albeit still necessary) in the process of developing an in-depth understanding of a new idea. And while being able to apply one's knowledge to future and current events (in the form of predictions or underlying explanations) is a skill that is crucial to the process of developing new scientific understandings, scientific ideas are ultimately abstractions that can be explored independent of context, and so the component involving the defining, describing, and connecting of the many scientific concepts, procedures, processes, and representations is a component that could rightfully be considered one of the most important components of SMD. Finally, the testing of knowledge compatibility gets at the very heart of science in that it is a component that explores whether scientific knowledge can be generalized from one context to another; this component is absolutely vital to developing new scientific understandings because it helps students understand how principles that have been inferred from particular experiments are potentially valid in many other contexts, and therefore might be applied to a wide variety of scientific phenomena.

In addition to some of the components being more important, they can also be cognitively more challenging. It has been well-documented, for instance, that students have great difficulty with the metacognitive processes of examining and regulating their own thinking (Bruer, 1993), one of the more important examples of which is the desire and ability to ensure that one's knowledge is valid in a wide variety of circumstances. Testing for knowledge compatibility is therefore expected to be a component that would be challenging for many students. Another potential cognitive difficulty comes from that fact that student thinking is often highly contextualized (diSessa, 1988; Roschelle, 1995), and so one would expect students to have a great deal of difficulty with defining, describing, and connecting the many abstract concepts, procedures, processes, and representations that are connected with science.