CHAPTER 2: CONCEPTUAL FRAMEWORK

Overview

In learning science, individuals increase their understanding of scientific concepts and procedures through a complicated interaction of individual cognitive processes, social guidance, and the structure and organization of the learning environment. In this chapter, because of this study's emphasis on sense-making discussion, I clarify this complex interaction by examining how sense-making discussion (SMD) interacts with learning and cognition. I then examine how SMD -- a form of social interaction and discourse -- are likely influenced by the personal, group, task and contextual factors embedded within the classroom environment. These factors are summarized and explained in this chapter so that, when I attempt to identify the factors that influence the particular small-group discussions in this study (Chapter 6), I have an initial list of factors with which to begin my "factors" investigation.

Sense-Making, Discourse, Collaboration, and Factors Affecting Sense-Making Discussion

An analysis of SMD is an analysis of spoken words -- words that somehow reveal the nonverbal sense-making in which students engage. However, SMD is not "just" evidence for scientific thinking in the brains of particular students. One must also remember that an important way to learn and develop an understanding of scientific methods is through participation in group discourse. In these interactions -- some collaborative, some not -- learners have the opportunity to exchange ideas, provide guidance, talk science, and appropriate (for their own use) the many scientific methods and concepts revealed in peer discussion. Therefore, SMD should not only be considered as evidence for scientific thinking in THIS student or THAT student; it should also be valued as a means for each group member to develop an understanding of scientific methods by way of participation in a shared discourse -- a discourse which uses language as a means for fostering learning and development.

Naturally, a good deal of sense-making consists of nonverbal processes directed at making sense of new concepts as group members read, perform actions, and engage in silent reflection. Sense-making discussion, on the other hand, arises only during verbal exchanges between group members -- and so SMD may rightly be considered as the process that connects nonverbal sense-making to group discourse.[1] The role of collaboration is especially important in group sense-making because, ideally, SMD is generated as groupmates share their ideas and thought processes with the purpose of achieving jointly shared goals: learning, finishing the activity, and so forth. However, it must also be recognized that SMD can be generated in non-collaborative contexts (e.g., two group members competing against one another to get the "correct" answer) -- but whether this sort of SMD is healthy for the group is a matter that remains to be seen.

---

[1]Theoretically, some researchers might argue that certain forms of SMD do not fall into the category of "discourse". For example, some might argue that there are instances when a person merely "thinks aloud" without intending to engage in conversation with another person. However, because of the fact that all of the participants in this study worked in small groups, and also given the fact that group members could respond to any and all utterances in the group -- regardless of their intent -- all of the verbalizations in this study were considered to fall under the category of "discourse".

Given the clear interrelationships between discourse, collaboration, and verbal and nonverbal sense-making, my conceptual framework for SMD contains precise definitions of these constructs, as well as a more detailed description of how these constructs are linked to one another. First, however, my conceptual framework begins with a summary of the relationships between sense-making and the learning process, a summary which leads into a general discussion of the social origins of knowledge. In addition, because of my particular focus on factors affecting SMD, my framework describes those factors known to affect SMD in particular contexts, as well as those factors likely to affect SMD because of their effect on collaboration, discourse, and nonverbal sense-making. Ultimately, this broad framework of factors is utilized to validate whether these factors have a large effect on the group SMD in this particular study, and also to determine whether any additional factors influence group SMD beyond the list of factors already documented.

Learning and Sense-making

Research has shown us many things about the nature of learning. It is a gradual process (Roschelle, 1995) -- one where, to be meaningful, new information must be connected to existing knowledge structures (Hiebert & Carpenter, 1992). Constructing a conceptual understanding of a new topic is an effortful undertaking (Norman, 1993; von Glasersfeld, 1984); clearly, developing an understanding of unfamiliar physical concepts requires a lot of reflection. Despite this fact, research has shown that learners often construct an understanding of a new concept by automatically filtering the concept into an existing knowledge structure -- whether or not this happens to be the appropriate thing to do. (In other words, learners often don't recognize -- or, perhaps, don't take the time to realize -- that new concepts are sufficiently different from old concepts that they require major changes to existing knowledge structures.) This process of understanding by automatic application of existing knowledge structures is what Hatano (1998) calls *schema application*, whereas the active, complex process of making sense of new information is known as *comprehension activity* (Hatano, 1988, 1998; Hatano & Inagaki, 1987, 1991). With the exception of a few modifications to Hatano's framework, as outlined in Chapter 4, comprehension activity is the model for nonverbal sense-making in this study.

Because sense-making discussion has its roots in discourse and collaboration, an issue that has particular relevance to SMD is the issue of whether learning is an individual, social, or contextual process. Currently, accounts of learning often focus on one of two types of explanations: a) learning as an act of individual cognition (e.g., Anderson, 1983; Piaget 1952, 1969; von Glasersfeld, 1984), or b) learning as a social process of enculturation (e.g., Lave, 1988; Rogoff, 1995). It has become obvious that the integration of an individual model of cognition with a sociocultural model is not an easy task (Fosnot, 1993; O'Loughlin, 1992, 1993). Despite this difficulty, I base my own theoretical framework for learning on the assumption that both views are necessary to capture the many factors that affect the learning process (Cobb, 1994; Sfard, 1998). Considering the student from an individualistic perspective helps to explain the effects of beliefs, attitudes, and prior knowledge on the process of knowledge construction. A focus on the individual also provides insight into the results of learning (i.e., what the individual takes away from learning tasks). Also important, though, is the sociocultural account of learning, which allows us to widen our vantage point to include learning's broader context. Treating learning as a sociocultural activity provides great insight into the effect of social interactions and cultural artifacts on people's attempts to learn new concepts and integrate themselves into a community of learners.

The Social Origins of Knowledge and Learning

Social Interactions and Guidance

One of the most prominent sociocultural accounts of learning is given by Vygotsky (1986, 1987). He believed that each learner has a zone of proximal development (**zoped**) for every task domain, where the zoped is defined as "the distance between the actual developmental level as determined by independent problem-solving and the level of potential development as determined through problem solving under adult guidance or more capable peers" (Vygotsky, 1987, p. 86).[2] Guidance is a key concept in Vygotsky's theory of learning because he argues that problems which can be solved with guidance today are the problems that can be solved independently in the future (Griffin & Cole, 1984). In other words, ideally, guidance is eventually internalized by the learner (although not directly), enabling him or her to appropriate peer- or adult-modeled concepts and

---

[2]Learners have a number of zopeds, each tied to a specific type of task or type of problem solving that the learner is engaging in. These task domains can be very broad, requiring extensive knowledge and expertise, or very narrow, focusing on a single skill or a tightly bounded domain of knowledge.

procedures and use them independently at a later date. Vygotsky's (1986) own work showed that children who were supposedly at the same level of development -- "same," in this sense, meaning that the children could perform equally as well on tasks done independently -- varied quite a bit in terms of what they could achieve with the help of a guiding adult. Based on this result, Vygotsky concluded that these children were actually at various stages of development -- regardless of their identical performance on independent tasks.

Clearly, a child's skills which are either already developed or under development are central to that child's zoped. Still, one must not forget that a child's zoped involves an interaction between at least two people: the child and the adult or guiding peer. With this in mind, one must recognize another factor sure to affect a child's ability to learn from guidance: the knowledge and abilities of the guiding adult or peer. That is, Vygotsky's notion of the zoped must be expanded to encompass the abilities of both the child *and* the guiding adult. This point is clearly demonstrated in a study by Thompson and Thompson (1994, 1996), in which they describe a middle school teacher's attempt to teach the concept of rate to a student. What they found was that one of the researchers was able to help the student develop a conceptual understanding of rate, whereas the teacher could not. Although the middle school teacher had a firm grasp of the concept of rate, he was unable to provide appropriate guidance because he did not understand the conceptual difficulties that the student faced, nor did he understand the language or activity he should use to help the student improve her understanding. Their findings suggest that three elements -- knowledge of the concept or task, an awareness of learners' preconceptions and the conceptual difficulties they will face while learning the new concept or task, and a workable plan for helping learners change their preconceptions and overcome conceptual difficulties -- are essential for providing guidance that will lead to the development of conceptual understanding.

Finally, despite my stressing of adult-child interactions, one must remember that group settings also provide many forms of guidance for the learner. Hiebert and Carpenter (1992) suggest that allowing students to work in groups is a valuable pedagogical tool because it enables students to experience the entire process of solving problems while only being responsible for certain aspects of the solution. This suggests that if students are able to observe the activities of other group members, then group work can serve as an intermediate step to independent problem solving. Cole (1996) used a similar notion to teach children with learning disabilities to read. In his study, children met with two adults in a group setting. After reading each paragraph silently to themselves, group members took turns performing different tasks, such as stating the main idea of a passage or identifying and asking about words that were hard to read. Thus, the different subtasks of reading were made explicit to the children, allowing them to participate in the act of reading without having to master all of its intricacies. As the result of such guidance, children who participated in the program improved their reading skills significantly.

Classroom and Small-Group Expectations and Obligations

Thus far, the discussion of the role of sociocultural factors in learning has been limited to social interaction and guidance. The other main thrust of the argument -- that learning is a process of enculturation into a community[3] -- has so far gone unaddressed. This omission is remedied by the inclusion of ***expectations*** and ***obligations***, two means by which behaviors, thoughts, and actions of individuals are mediated by the traditions and values of a community. Cobb, Wood, and Yackel (1993) refer to this relationship as "reflexive" to emphasize that interactions between the individual and the community have a developmental effect upon each; in other words, an individual's thoughts and actions both contribute to and are guided by a community's expectations and values. In the present study, I consider two separate communities: the classroom, and the small group.

Expectations and obligations in the classroom. Expectations are based on the community members' shared understandings of how "normal" community members should act as they engage in joint activity. If the community is a classroom, one would find expectations that prescribe learning, discussion, and problem-solving activities, among others.

Following are three examples of classroom expectations (Cobb, Wood, and Yackel, 1993). And, although students do have some influence on classroom expectations, the presence or absence of these particular

[3]I recognize, of course, that there is no one "community". Each individual "learns" to be a member of any number of communities: one's country, one's local community, one's association with a particular gender, one's classroom, and so on.

expectations are largely determined by the words and actions of the classroom instructor.

- Learning might be expected to be either a process of negotiation or a process of didactic transmission.
- Classroom discussions might be expected to be either constant testings for correct answers or explorations of students' current understandings.
- Students might expect acceptable solutions to problems to be ground in either qualitative reasoning or quantitative manipulation.

<u>Expectations and obligations in a small group</u>. One would expect small-group expectations and obligations in a science classroom to address a number of student activities, including experimental procedure, scientific argumentation, problem-solving, and general social interaction. For example, the following obligations were found to affect the group-based physics learning of preservice teachers in an undergraduate classroom (Johnson, 1999):

- In recording their explanations on a computer, group members were obligated to type responses that were acceptable to each group member.
- When describing physical phenomena, students were obligated to speak in terms of observable results (e.g., the motion of repelled magnets) rather than unobservables (e.g., current or charge).
- In the process of model development, students were obligated only to admit evidence that was obtained from classroom experiments.

The sphere of influence of classroom and small-group expectations. Beyond the obvious statement that expectations and obligations do exist, a second issue revolves around the extent to which community members are bound by the expectations of their community.

One interesting aspect of community activity is that there are some expectations so totally ingrained into the members' daily thoughts and activities that they appear to act below the level of consciousness (Boas, 1904; Boas, 1911, as cited in Stocking, 1966). Examples of implicit expectations are: driving on the right side of the road (for Americans), wearing clothes, and maintaining personal space.

In cases where members *are* relatively conscious of community expectations, there is no doubt that community members are able to step beyond the bounds of community expectations and "do their own thing".[4,5] Such over-stepping may actually influence the expectations themselves, since, as previously discussed, individual and community development is a two-way street. Yet, people who violate community expectations (conscious or no) are often either explicitly punished, socially shunned, or both. More often than not, either reaction is enough to keep a person in line with their community's expectations.

---

[4]Practitioners who take a cultural approach to education (e.g., Bowers & Flinders, 1990) often make the point that the first step in changing established practices is to make subconscious expectations conscious through the processes of reflection and discussion.

Scientific Discourse in Small Groups

Science teaching, in part, is the process of bringing learners into a community (Lave, 1991; Lave & Wenger, 1991) -- a community which uses a set of agreed-upon technical terms, concepts, and mathematical and experimental procedures to conduct its business of discussing and investigating the physical world. For this reason, an important goal of science education is to get students *talking science*, meaning the following:

> "Talking science" does not simply mean talking *about* science. It means *doing* science through the medium of language. "Talking science" means observing, describing, comparing, classifying, analyzing, discussing, hypothesizing, theorizing, questioning, challenging, arguing, designing experiments, following procedures, judging, evaluating, deciding, concluding, generalizing, reporting, writing, lecturing, and teaching in and through the language of science.
>
> (Lemke, 1990, introduction, p. ix) [italics in original].

While "talking science" during small-group, discussion-based activities, students use words to mediate and drive their scientific investigations. Therefore, with language playing such an important role, it is only natural to consider the form and content of the students' conversations from a *discourse* perspective. In particular, discourse theory provides insight into two important issues relating to the construction of scientific understanding in small-group activities: a) the structure of student discourse, and b) the purpose of student discourse.

---

[5]It might also be the case that, in following the expectations of one community, a person violates the expectations of a separate community in which s/he is also a member. It is likely that

Structure of Student Discourse

Discourse is a language-based activity in which people's expectations of how discussion normally proceeds mediates their conversations, actions, and constructions of meaning. These expectations take the form of *activity structures* (Lemke, 1990), which are sequential lists of steps normally followed by participants in the discourse.

For instance, students and teachers commonly engage in an activity known as Triadic Dialogue, in which teachers ask questions, call on students, and evaluate answers (Lemke, 1990, p. 217). The following sequence is typical for this activity:

Table 2-1. Typical activity structure for a triadic dialogue.

Action	**Example of Action**
[Teacher Preparation]	Teacher draws diagram
Teacher Question	Teacher poses question to class
[Teacher Calls for Bids]	Teacher asks students to raise hands
[Student Bid to Answer]	Student raises hand
[Teacher Nomination]	Teacher points at student
Student Answer	Student answers question
Teacher Evaluation	Teacher nods head in assent
[Teacher Elaboration]	Teacher clarifies student's answer

Note. Bracketed steps are optional (i.e., may or may not appear) in this activity structure.

---

the expectations of overlapping communities have different weights in different contexts.

As related to the present study, it is important to note that Lemke's research on discourse was conducted in traditional classroom settings, and that therefore the majority of his resulting activity structures (e.g., Teacher-Student Debate, Triadic Dialogue; see Lemke, 1990, pp. 217-218) explicitly involve the teacher. While these structures may be somewhat relevant to small-group discourse -- say, for example, when a teacher stops to question and guide the members of a group, or perhaps when a group member takes on the "teacher" role -- the structures that are most pertinent to the present study are those that guide groups' scientific conversations when teachers are not present. As a first step in this direction, Lemke (1983) summarizes the Groupwork/Labwork activity structure as it normally proceeds over the course of an entire class period.

Groupwork describes those situations where students are placed in small groups -- the teacher's expectation being that the group members will then collaborate on the group task. Labwork is similar, except that lab activity uses special materials (i.e., the equipment used for laboratory experiments). The Labwork structure typically follows the following four-step sequence: Preparation, involving a review of concepts, procedures, and materials; Getting Set Up, during which time the lab materials are distributed; Discussion, in which students make measurements, report results, and discuss conclusions; and Cleaning Up, at which point the lab materials are put away.

Yet, while the above description is useful as an overall framework for student behavior as they engage in small-group groupwork/labwork, we are still left with the issue of what students in small groups actually say to one another on a minute-by-minute basis. Unfortunately, despite this need, activity structures have not yet been documented at this level of detail in the existing literature on scientific discourse. However, there does exist a more general framework for the ways in which contributions to group discourse flow from one speaker to the next. Based on the idea that the spoken words of the current speaker are dependent on previous contributions to the conversation, it has been shown that small-group discourse typically consists of some combination of the following three discourse moves: initiating discussion of a new issue, eliciting an additional contribution, and extending and qualifying a previous contribution (Barnes & Todd, 1977, 1995).

Initiating discussion of a new issue. Usually following a pause in talk, initiations serve to introduce a new topic for discussion. They may take the form of declarations ("I think that voltage comes from batteries!") or questions ("Where do you think that voltage comes from?"), and often contain the phrases "I think...", "I don't think...", or "Do you think...?".

Eliciting an additional contribution. To help maintain and support coherent discourse, group members often invite each other to talk. These invitations (elicitations) are requests for group members to do one of four things: continue what they are saying, expand on a previous remark, support the speaker's opinion, or provide additional information.

Extending and qualifying a previous contribution. When a group discovers a valuable topic, strategy, or idea, one group member will often take up the topic/strategy/idea from another member and extend it. The extension may be as simple as finishing another person's sentence, or something more substantial such as adding to or transforming the previous contribution. Invariably, extending an idea qualifies it in some manner, often by pointing out the original idea's range of applicability or complexity.

Finally, while the above discourse moves are useful descriptions of how small-group discourse normally proceeds, one should not be left with the impression that discourse is limited only to these three moves. Instead, group discourse is a fluid exchange in which the rules of conversation are often ignored or broken (Lemke, 1990). In a second's time, a simple initiation might transform into a full-scale debate; similarly, a teacher might sacrifice the integrity of an activity structure in order to admonish a student for answering out of turn. Strategies that move participants away from strict adherence to activity structures and the maintenance of free-flowing discourse include interrupting, declining to answer a question, and asking digressing questions (Lemke, 1990, pp. 219-220).

Purpose of Student Discourse

Some activity structures meet a specific need, while others are general forms which are able to serve a number of different purposes. For example, the Triadic Dialogue activity structure does not in and of itself have any particular function; it might be used to review old material, go over homework, or work through the solution to a new problem (Lemke, 1990, p. 49). Given this ambiguity, it becomes necessary to examine the reasons why students in small groups say the things that they do. Here, these reasons are framed in terms of ***purposes***.

Within a Groupwork/Labwork activity structure, the primary purposes of scientific discourse are to undertake negotiations of actions, materials, status, and meaning (Shepardson, 1996). Each negotiation, in its own way, is meant to control other group members' behavior and influence the direction of the discourse and activity. A negotiation of *actions* is where one student's interaction[6] elicits an action (e.g., taking a measurement, connecting two wires, drawing a diagram) from one or more of the other students in the group. A negotiation of *materials* is a sequence of interactions that results in the sharing or distribution (or not, as the case may be) of physical materials such as worksheets, writing implements, scales, and springs. A negotiation of *status* is a sequence of interactions that grants authority to one group member. Finally, a negotiation of *meaning* is a sequence of interactions that results in the sharing or communication of scientific phenomena (i.e., scientific concepts or terminology).

In his study of first-grade children engaged in small-group science activities, Shepardson (1996, p. 176) found that, out of 96 total child-child interactions, the frequency of each type of negotiation (plus social/off-task interaction) was as follows:

[6] *Interaction* in this context refers to both verbal and nonverbal communication.

Table 2-2. Distribution of negotiations of status, action, materials, and meaning from Shepardson (1996).

Nature of interactions	Number
Negotiation of status	5
Negotiation of action	23
Negotiation of materials	34
Negotiation of meaning	0
Other (social/off-task)	34

Striking is the fact that these children did not engage in any negotiation of meaning on their own. The relevance of this result to the present study is clear when we realize that SMD is the very process by which group members negotiate the meaning of new scientific concepts. The relevant result, then, is that the children in Shepardson's study did not engage in any SMD. In this light, it was of great interest to determine whether the older students in the present study would engage in negotiations of meaning through SMD, or whether they would instead be primarily concerned with negotiations of actions, status, or materials -- as in the study by Shepardson.

Nonverbal Sense-making: Comprehension Activity

Having portrayed SMD as the means for students to negotiate scientific meaning in small groups, the time has come to explicitly define the model for nonverbal sense-making in the present study: Giyoo Hatano's *comprehension activity*. It was this nonverbal sense-making model --

especially its four components, defined below -- that served as my initial framework for SMD, although careful analysis of the small-group discussions in this study resulted in a number of changes (both minor and major) to the model, all of which are outlined in Chapter 4.

Introduction

As a general rule, a person comes to understand new information in one of two ways. First, a person might filter new information into pre-existing knowledge networks. These networks are knows as schemas, with the process itself known by various (essentially equivalent) labels: assimilation (Piaget, 1952; Piaget & Inhelder, 1969), accretion/tuning (Norman, 1993), and schema-application (Hatano, 1998). This type of understanding is appropriate and justified in the vast majority of cases, as in the instance where a man walks into his neighbor's kitchen and -- based on his visual perception of three objects -- appropriately filters these objects into "microwave", "stove", and "dishwasher" schemas, respectively. On the other hand, two hours later, that same man may spot a young lady on a downtown sidewalk and mistakenly filter the rough-looking, head-scratching woman into a "panhandler" schema -- when, in fact, the woman is merely a confused out-of-towner hoping that someone might stop and offer directions.

The second class of understanding, in contrast to the relatively automatic process of schema-application described above, is a complex, effortful process whereby a person modifies existing schemas or creates new schemas in order to accommodate new information. This process is known variously as accommodation (Piaget, 1952; Piaget & Inhelder, 1969), restructuring (Norman, 1993), or comprehension activity (Hatano, 1988, 1998; Hatano & Inagaki, 1987, 1991). Of these constructs, comprehension activity proved to be the most useful theoretical formulation of the active "understanding" process. This was the case for three reasons: a) its components had been explicitly defined, b) although applicable, in theory, to any content domain, it was seen as a model of *scientific* thinking, and c) Hatano and his colleagues had already undertaken numerous studies to determine the ways in which certain personal, group, task, and contextual factors affect comprehension activity.

Comprehension Activity Defined

Comprehension activity (CA) as defined by Hatano consists of the following four components.

1. Seeking of new information.

This component of CA encompasses requests for clarification, explanation, and general information, questions relating to what might happen if the current activity were extended, and the gathering of feedback through real and mental[7] scientific experiments.

2. Generation of inferences.

This sense-making process involves establishing conceptual connections. The requirement that explanations must be original is important because explanations that are recalled from memory fall under the category of "retrieving prior knowledge", below.

[7]I.e., *gedanken*, or thought experiments.

3. Searching for knowledge compatibility.

This category encompasses comparisons between bits of knowledge in order to achieve consistency.

4. Retrieval of prior knowledge.

This category represents the recall of familiar explanations, concepts, or phenomena.

Sense-Making Discussion and Nonverbal Sense-making

The relationship between SMD and nonverbal sense-making (i.e., comprehension activity) has, as yet, not been specified other than to say that the two constructs are somehow associated with one another. In fact, if the only goal of the present study were to count the number of times that instances of verbal sense-making appear in small-group discourse, the omission of the details of the verbal-nonverbal relationship wouldn't pose any major problems. But, with my focus on the factors affecting verbal sense-making, the connection between SMD and nonverbal sense-making (CA) needs further description because certain factors have a large effect on SMD precisely because of their tremendous influence on nonverbal, individual sense-making.

Superficially, the relationship between verbal and nonverbal sense-making is clear-cut: verbal sense-making is, one would think, nonverbal sense-making simply spoken aloud. On closer inspection, however, this description tells only a small fraction of the story. At times, verbal and nonverbal sense-making can be thought of as occurring almost simultaneously -- seen, for example, as a group member speaks aloud her thoughts and mental processes as she searches for connections between new information and prior knowledge. On the other hand, it is quite possible -- during small-group interaction, especially -- for verbalized sense-making to either lead or lag nonverbal comprehension activity. During the first 5 minutes of an activity, for instance, a student might make a connection between force and an object's change in motion. However, this connection might not come up in conversation until the point when, ten minutes later, the student explains his understanding of force to a fellow group member. In the opposite case -- with verbal sense-making leading nonverbal -- it may be that one student guides a student through the sense-making process ("Wait, how do you know that the forces on the two objects are the same -- are you sure?"), with the guided student's nonverbal sense-making not occurring until he reflects back on the conversation with his more-knowledgeable partner.

An issue implicit in the discussion of the delay between verbal and nonverbal sense-making is the degree to which a person's nonverbal sense-making becomes verbalized. It is almost certainly true that the entirety of a person's nonverbal sense-making never becomes fully verbalized -- even when the two are nearly simultaneous. It is also likely that, in some small-group interactions, a group member may not verbalize *any* of her nonverbal, individual sense-making. There will also be instances when students engage in very little sense-making -- possibly even none. In these instances, students will not be seen to engage in SMD because, in the absence of peers or adults to guide them through the sense-making process, there is nothing to verbalize.

Collaboration in Small Groups

In structuring small groups to engage in sense-making activity, one must not forget that placing 3-4 students in close proximity to one another does not guarantee that students will collaborate, stay on-topic, or even speak to one another. Multiple discourses may arise within a single group -- with, for example, two separate pairs of students (of a four-student group) carrying on two completely different on- or off-task conversations. Other times, students might be disoriented, confused, or even confrontational (Lemke, 1990). Moreover, when learning does become a group's primary focus, group members might adopt competitive or individualistic stances toward learning, rather than adopt the "we're all in this together" attitude that helps students work together to achieve jointly shared goals.

At the most basic level, the result of uncooperative behavior in groups is that students are unlikely to engage in any sort of constructive discourse -- let alone the kinds of sustained sense-making discussion that educators would prefer to see in their small groups. Small-group collaboration, then, can be seen as a skeleton of support that drives and nurtures peer guidance, group conversation, and, in turn, the sorts of explaining, hypothesizing, and elaborating (i.e., verbal sense-making) that leads to the development of new scientific understanding. Therefore, an investigation of factors affecting SMD in small groups must include an analysis of whether the participating groups are able to establish and maintain a collaborative atmosphere. This is especially true if those factors which are assumed to have a large effect on SMD (content knowledge? opportunities for reflection? subject matter interest?) only come into play when group members are first able to interact with one another in a cooperative, respectful manner.

On the matter of collaboration and group learning, prior research has shown that each group member is likely to increase his or her understanding of the topic at hand as long as the group possesses the following four characteristics (Johnson & Johnson, 1994; Johnson, Johnson, & Smith, 1991).

- Group members actively promote each other's learning and achievement
- Group members assist, support, and encourage their fellow group members
- Group members are held accountable for their own individual learning
- Group members possess the interpersonal skills necessary to work cooperatively in groups

When groups members don't actively promote each other's learning, they are much more likely to work independently or competitively -- the result being that students are less prone to share knowledge and provide guidance for one another. The assistance and support, as defined by Johnson, Johnson, and Smith (1991), takes the form of students "explaining to each other how to solve problems, discussing with each other the nature of the concepts and strategies being learned, teaching their knowledge to one another, and explaining to each other the connections between present and past learning" (Chapter 1, p. 19). The purpose of establishing individual accountability is for group members to take it upon themselves to learn the material associated with the group task. To ensure that this goal is met, students must come to understand that letting others do all the work is neither useful nor appropriate. Finally, to work together successfully in a group, students need to employ a wide range of interpersonal skills. These include leadership, trust-building, and conflict management skills. When linked to promotive interaction, these skills ensure that explanations, elaborations, and discussions don't become usurped by power struggles, petty arguments, and other unproductive breakdowns in student discourse.

Factors Affecting Sense-Making Discussion

Sense-making discussion is a scientific discourse that ideally is an interaction between nonverbal sense-making, discourse, and collaboration. For this reason, factors that affect a group's progress in these three domains are sure to affect the group's SMD. After all, students who don't engage in nonverbal, individual sense-making (for whatever personal, social, and contextual reasons) would also seem unlikely to engage in SMD. Likewise, the different types of group conversation (e.g., off-task, negotiations of meaning, negotions of status, etc.) all contribute to the amount and quality of a group's SMD. Thus, my conceptual framework for the factors likely to affect SMD includes those personal, group, task and contextual factors affecting nonverbal sense-making, small-group scientific discourse, and small-group collaboration. As stated previously, this broad range of factors lays the groundwork for helping me to achieve the following goals: a) to validate whether these factors have a large effect on the group SMD in this particular study, and b) to determine whether any additional factors influence group SMD beyond the list of factors already documented.

Overview

As outlined above, verbalized sense-making can either lag, lead, or occur simultaneously with nonverbal sense-making. The implication of the possible relationships between verbal and nonverbal sense-making is that factors can affect sense-making discussions in three ways:

1. Factors can affect the amount and type of nonverbal sense-making in which students become engaged, and therefore can affect the amount and type of sense-making that students are able to verbalize
2. Factors can affect whether or not students communicate their nonverbal sense-making to other members of their small group
3. Factors can affect whether students can be socially guided to engage in sense-making activity

I now outline the many personal, task, group, and contextual factors that are likely to have one or more of these effects on small-group SMD in this study.

Personal Factors Affecting Sense-Making Discussion

Cognitive criteria for sense-making. Hatano and Inagaki (1987) list four independent criteria that must be met before an individual will engage in comprehension activity (nonverbal sense-making). These criteria are:

- The person must be free from urgent need.

- The person must see comprehension of the target rule or procedure as important and possible.
- The person must be capable of recognizing the inadequacy of their comprehension.
- The person must experience cognitive incongruity.

The first condition -- freedom from urgent need -- addresses the idea that students will only engage in CA if they are free from such pressures as hunger or the need to attain a high grade on an examination.

The second condition makes explicit the notion that students must believe that comprehension of the target rule or procedure will be worth the amount of mental effort that they will have to invest (due to their interest in the subject matter, for example) and that they must feel confident in their ability to achieve comprehension in order to persevere in the face of confusion and difficulty.

The third condition is a statement of metacognitive awareness: that the student who cannot see fault in his or her understanding of a concept or procedure has no reason to modify that understanding.

Lastly, to elaborate on the fourth condition for CA, Hatano and Inagaki believe that three types of cognitive incongruities motivate a person to pursue insight through comprehension activity. These three incongruities are (Hatano, 1988, pp. 58-59):

• surprise, which is induced when a person encounters an event or information that disconfirms a prediction based on prior knowledge

• perplexity, which is induced when a person is aware of equally plausible but competing ideas

• discoordination, which is induced by the awareness of a lack of coordination among some or all of the pieces of knowledge involved

Student goals. Student goals in educational contexts include learning goals, performance goals, social goals, and others (Wentzel, 1993). Each type of goal affects comprehension activity in a different way.

A person with a *learning* goal intends to gain a deeper understanding of the concept or task at hand. Presumably, the person who values this goal will engage in sense-making to the best of his or her ability. A person with a *performance* goal focuses on achievement, which translates into a desire to demonstrate one's knowledge or skill after it has been acquired (Brophy, 1987). The adoption of performance goals (driven by grades on classroom examinations, extrinsic rewards, and classroom norms) is widely considered to have a negative effect on learning. In particular, rewards have been shown to elicit negative attitudes toward the "rewarding" activity and suppress intrinsic academic motivation (e.g., Kohn, 1996). Also, Schiefele and Schreyer (1994) (cited in Schiefele & Rheinberg, 1997) found that extrinsic (i.e., performance-based) motivators correlated with surface-level learning strategies such as analytical, fact-oriented, and rehearsal learning strategies. Consequently, students with performance goals are less likely to engage in any sense-making, whether it be nonverbal or verbal.

At their core, *social* goals (the last of the goal types considered here) involve satisfying the desires and expectations of particular people or society at large. Typical social goals (Urdan & Maehr, 1995) include social approval (e.g., gaining the approval of others), compliance (e.g., being a "good boy" or "good girl"), and becoming a productive member of society. One would expect different social goals to have different effects on SMD: some positive, some negative, and some having no effect at all. Certain peer groups, for example, might be motivated to achieve low grades in order to distance themselves from the "uncoolness" of school. Other peer groups might seek to perform well on exams to impress teachers, parents, and other peer group members. In both cases, improving one's standing in the eyes of others is the primary goal, although one would expect sense-making to be common only in the latter case.

Prior knowledge. Some researchers argue that student conceptions are coherent, firmly held concepts upon which students base their scientific reasoning in many different physical contexts (McCloskey, 1983; Carey, 1988). Others argue that "conceptions" are best represented as loosely connected bits of knowledge, and that reasoning is a process largely dominated by the spontaneous generation of context-driven explanations (diSessa, 1988; Roschelle, 1995). Regardless of these differences, one assumption common to both theories of student knowledge is that the learning process stands or falls on the interaction of new information with previously existing knowledge. This previously existing (prior) knowledge enters the sense-making process in a variety of forms: analogies, anchoring conceptions, background information, firsthand experience, and the host of topic-specific concepts, facts, and procedures that are helpful and informative in exploring a new idea. Therefore, prior knowledge likely plays a role in determining whether students are able to contribute significantly to sense-making discussions. If a group is discussing the concepts of force and gravity, for example, then students who have watched a number of Nova specials on gravitational pull would likely have much more to contribute than students who have never been directly exposed to these concepts.

Subject matter interest. It is almost a truism that students who are interested in a topic will be more likely to engage in sense-making discussion about that topic than students who do not hold the same interest. Personal interest, such as a student's general interest in science, is something that develops slowly over time and tends to have long-lasting effects on a person's knowledge and values (Hidi, 1990). In this case, part of the relevant effect is that students with an interest in science (or an interest in a particular science topic, such as gravity) will likely have developed a value system which considers scientific concepts to be ideas that are worth knowing and understanding. Therefore, having met one of the necessary requirements for sense-making -- seeing comprehension of the target concept/procedure as important -- there is a high likelihood that students who are generally interested in science will engage in sense-making when confronted with cognitive incongruity relating to scientific ideas.

Another relevant effect of general science interest on sense-making is that interest in science naturally coincides with knowledge of science. Unsurprisingly, people who value science typically amass a large amount of scientific knowledge. Therefore, it is not just the valuing of scientific concepts that contributes to one's propensity for sense-making, but also the fact that interested students are more able than uninterested students to draw on relevant science knowledge as they clarify ideas, provide evidence, and challenge others' ideas. That is, during their group discussions, students with an interest in science can draw on the scientific ideas and experiences that they've gathered from their extracurricular science activities, while uninterested students -- because they haven't been exposed to these ideas, or haven't had the same experiences -- are mainly left to draw on their classroom experiences as they participate in small-group SMD.

Task Characteristics Affecting Sense-Making Discussion

Task goals. Some task goals are more effective than others in guiding and supporting students' SMD. The solving of novel, ill-defined problems, for example, is especially valuable in provoking deep thinking about a problem's underlying physical phenomena (Hatano, 1988; Heller & Hollabaugh, 1992). This is because, in the process of solving the problem, students are forced to engage in sense-making in order to answer the following sorts of questions for themselves: What is the actual problem here? (I.e., What is our problem-solving goal?) What physical concepts and principles apply? How should we plan and implement a solution? Familiar, well-defined problems, in contrast, allow students to avoid sense-making by instead engaging in the efficient use of well-established experimental and mathematical procedures (Hatano, 1988).

Accompanying artifacts. A sociocultural perspective reminds us that science learning is mediated by a number of inherited cultural artifacts.

These include language, scientific laws, experimental procedures, and mathematical formulas, all of which might be classified as intangible artifacts. Another class of artifact is the physical artifact -- the instrumentation and equipment that learners use to measure physical phenomena, record experimental results, and illustrate their scientific understandings. Such objects, whether they be in the form of calculators, rulers, or worksheets, affect a group's SMD in many ways.

One way that physical artifacts affect sense-making is that they can provoke student thought (Norman, 1993). Just as peer or teacher guidance can prompt students to provide additional evidence, elaboration, and explanation, so too can worksheets and computers guide students to reflect more deeply on the underlying concepts and phenomena of the group task. In particular, *reflection prompts* (Davis, 1998) in the form of directed questions, open-ended questions, and unfinished sentences can affect student comprehension, sense-making, and learning. Some prompts are as basic as "Explain your reasoning", while others are more specific ("What experiences have you had to make you think the way you do?", CPU project, 1999) or more open-ended ("Right now, we're thinking...", Davis, 1998). The process of thinking about and discussing such questions/directives clearly gives students the opportunity to engage in (and verbalize) sense-making when they might otherwise put their effort and attention elsewhere.

Aside from direct prompts to reflect, artifacts can also provide conceptual guidance and support. They do so by directing the students' attentions to relevant concepts or procedures -- concepts or procedures that the students might not consider if the artifact were not present. For instance, consider a computer program that allows students to manipulate a satellite's initial velocity and position in order to examine the effects of those manipulations on the satellite's orbital trajectory around the earth. The conceptual guidance in this instance is that the program designers have implicitly guided the learner into thinking that velocity and position are the two variables most relevant to the satellite's trajectory. Students are not given the opportunity to change the satellite's temperature or color, for instance -- because, in the eyes of the scientific expert, those variables are not particularly relevant to the trajectory of the satellite. It is precisely this sort of conceptual support that is employed by well-designed curriculum materials and educational software to help students reflect on, discuss, and reconsider their ideas about physical concepts and processes.

A general principle that encompasses the educational support and guidance that is provided by artifacts (and teachers) is the principle of ***scaffolding***. The idea is that artifacts (such as curriculum materials) provide the support and guidance (i.e., provide the scaffolding) that students need to complete tasks that they could not otherwise perform on their own -- just as real-life scaffolding allows construction workers to get at those high-up places that they could never reach on their own. Stated another way, recognizing that students have their own zones of proximal development, and that the tasks that students can do with help today are the things they can do on their own tomorrow, the implication is that the guidance that helps students move from their actual to their potential levels of development can come from either people (teachers, peers) or objects in the educational environment. The scaffolding associated with this guidance might be focused on encouragement, the directing of attention, providing important information, the setting of sequential task goals, or anything else that the students aren't initially able to provide for themselves (Griffin & Cole, 1984).

Intrinsic motivation of the task. Another issue addressing the influence of educational activity on learning and sense-making is the degree to which the group task is intrinsically motivating. Intrinsic motivation is defined as task engagement due to a task being "interesting, enjoyable, or otherwise satisfying" (Schiefele & Rheinberg, 1997, p. 254; see also Deci & Ryan, 1985). Some contributors to intrinsic motivation are: the degree to which the learner has control over the activity, task novelty, and personal relevance. Schiefele and Schreyer (1994; cited in Schiefele & Rheinberg, 1997) found that intrinsic motivation correlated with deep-level organizational, elaborative, and metacognitive learning strategies. Therefore, an intrinsically motivated student is likely to set learning goals and engage in sense-making.

However, as Norman (1993) warns, task enjoyment does not necessarily give rise to the reflective cognition necessary for the development of fresh understandings. People experiencing "flow" (Csikszentmihalyi & Hermanson, 1995), a state of arousal characterized by single-minded focus and immersion in an activity, may be engaged in pure sensory pleasure ("experiential cognition"; see Norman, 1993) rather than comprehension activity. In cases where a learning goal *is* formed, however, the "flow" state would seem to be ideal in maintaining task persistence and driving students to engage in the four components of comprehension activity.

Science content. A great deal of research has been conducted on students' initial ideas about various science topics, and also how student ideas develop as they try to learn those topics. Topics that have been researched extensively (e.g., Driver, Guesne, & Tiberghien, 1985) include light, electricity, heat and temperature, the particulate nature of matter, and force and motion.

One important aspect of the middle school curriculum in this study -- the Constructing Ideas in Physical Science (CIPS) curriculum -- is that, in designing the progression of activities in each curriculum cycle and unit, the curriculum developers had already taken into account the many ideas that students have about force and motion. For instance, it is common for students to believe that gravity on earth comes from atmosphere, magnetism, or the earth's spin -- and so the experimental activities in the "gravity" portion of the curriculum help students understand that atmosphere, magnetism, and the earth's spin could not be possible causes of gravity. Therefore, some of the problems that students have with traditional curricula -- including the fact that students' initial ideas about certain physical phenomena are never addressed -- likely will not appear in this study as factors that have a significant impact on SMD. However, there are bound to be topics that are more interesting or more challenging than other topics (and therefore have more impact on SMD than other topics) because students will have had more day-to-day experience with some of these topics than others.

Group Characteristics Affecting Sense-Making Discussion

Hatano (1988) argues that social interaction (through group problem-solving, for instance) is a natural way for students to perplex, surprise, and discoordinate each other -- thus provoking sense-making in many or all of the group's members. However, it isn't the case that all groups are equally as likely to engage in collective sense-making.

Group leadership and student roles. The degree to which students can interact with one another in small groups is dependent on the leadership style of (if one exists) the group leader, where the term *group leader* refers to the group member who typically directs the actions and discussions of the entire group. Richmond and Striley (1996) studied 10th graders as they performed small-group scientific experiments and discovered that the *inclusive* leadership style was the most effective in promoting scientific discourse and joint knowledge construction; leaders using this style would bring up an idea, ask group members for their opinions, and carefully consider their input. A less effective style for promoting collaborative discourse was the *persuasive* style, in which the leader would present an idea to the group and, if challenged, would attempt to persuade the others to convert to his or her point of view. The final leadership style -- one found to be ineffective, and even destructive to group sense-making activity -- was the *alienating* style, in which the leader would declare their strongly-held ideas and disregard input from the other group members.

Beyond the leadership role, other social roles documented by Richmond and Striley were: the *helper*, who cooperates with the leader to formulate and carry out group plans; the *active noncontributor*, who, in addition to engaging in large amounts of off-task behavior, also challenges and ridicules the other group members; and the *passive noncontributor*, who rarely participates in group activities and often copies their work from others.

Shared goals. Johnson and Johnson (1984) argue that, to ensure that students promote each other's learning to the fullest extent possible, the group activity should be organized in such a way that students all feel responsible for achieving the task goal. We have already recognized that students have their own individual goals (learning goals, social goals, etc.), but it needs to be further recognized that it is possible for the goals of one group member to be radically different from the goals of another group member. Therefore, one challenge in any group-based curriculum is to help group members adopt shared learning goals (Tudge, 1990). When this occurs, group members are working toward the same end (finishing the activity, learning, etc.), and are in a better position to help their fellow group members learn the material. Requiring students to produce a product that meets the satisfaction of all members, or requiring students to reach consensus (while formulating a hypothesis, e.g.) are two ways to ensure that group goals become aligned as much as possible.

Group expectations. It has already been established above, in the section on the social origins of learning, that group and classroom expectations can significantly influence a group's actions and ideas (e.g., Johnson, 1999). Therefore, I must leave myself open to the possibility that group and class expectations might significantly influence the small-group SMD in this study.

Collaborative skills. As described above, students who engage in significant amounts of SMD likely possess the leadership, discussion, and conflict management skills that help to engineer successful group collaboration.

Contextual Factors Affecting Sense-Making Discussion

The role of the teacher. Typically, as groups perform experiments and engage in discussion, the teacher goes from group to group to assess students' knowledge, help groups with experiments, and guides group members to a better understanding of the materials. Since the teacher is the primary source of authority in the classroom, one might expect these teacher interventions to have a significant impact on the sense-making discussions that occur once the teacher leaves the group. In fact, a small body of research verifies this expectation.

Shepardson (1996) found that, in a study of elementary students engaged in small-group scientific investigation, the teacher tended to negotiate meaning, status, and actions with individual students rather than with groups as a whole. The teacher's emphasis on individual negotiation rather than group negotiation/collaboration may have been one of the reasons why groups engaged in no sense-making discussion during the course of the study. In her review of the classroom conditions that support productive small-group behavior, Cohen (1994) pointed out that teacher guidance in the form of class instructions, the assigning of group roles (presenter, group facilitator, etc.), and the delegation of authority to particular group members could have either negative or positive effects on group cooperation and learning, depending on the exact nature of the teacher guidance.

Assessments. To ensure that group members learn the material and are in a position to provide guidance and encouragement for others, researchers have suggested that teachers should frequently assess the performance of each group member (Johnson & Johnson, 1984). Methods for obtaining these individual assessments include oral quizzing, randomly selecting students to provide answers, having group members edit each other's work, having students teach what they know to someone else, and having students use their new knowledge on a different problem. The hope is that these assessments will help students come to understand that letting others do all the work is neither useful nor appropriate, and also that participation in group sense-making discussions is both useful and worthwhile.

Summary

The purpose of this chapter was to: (a) provide an overview of sense-making discussion and learning, (b) describe the interaction between sense-making discussion, nonverbal sense-making, discourse, and collaboration, and (c) construct an initial list of factors that would be likely to influence the small-group SMD in this study.

As seen in this chapter, past research on sense-making, collaboration, and discourse has demonstrated that there are a number of factors that are likely to significantly influence small-group SMD.

In table form, these factors are as follows:

Table 2-3. Factors having a possible effect on the sense-making discussion in this study.

Personal factors		**Group factors**	
Student goals	Prior knowledge	Group expectations	Shared goals
Subject matter interest	Freedom from need	Leadership style	Collaborative skills
Cognitive incongruity	Metacognition	Student roles	
Comprehension: important and possible?			
Contextual factors		**Task factors**	
Classroom expectations	Role of teacher	Task goals	Science content
Assessments		Materials	Intrinsic motivation

It is this list that will initially be used to try to identify the factors that have the greatest influence on small-group SMD in this study.