Characterizing Discourse in Two Science Classrooms by the Cognitive Processes Demonstrated by Students and Teachers

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If you have feedback for us or would like to keep in touch with developments on the project, please check our website or send us an email at: devitobe@gse.harvard.edu or Tina_Grotzer@pz.harvard.edu.

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ABSTRACT

In the context of a broader study on how instruction on causality affects student understanding of density concepts, we videotaped and analyzed discussions in two eighth grade classes of different teachers to characterize patterns of interaction in each, and to identify teacher prompts that regularly elicited student responses that reflect conceptual understanding. Teacher and student contributions to classroom discourse were classified according to the cognitive processes and types of knowledge they reflected. Building upon work by Anderson and Krathwohl (2001) and others, we developed a taxonomy for classifying observable behaviors at a finely grained level suitable for discourse analysis. We report patterns in teacher contributions that yielded consistent trends in student responses as well as patterns unique to each classroom.

OBJECTIVES AND PURPOSES

Previous studies (e.g., Basca & Grotzer, 2001; Grotzer, 2000; Grotzer & Basca, 2003; Perkins & Grotzer, 2000, in press) have shown that augmenting traditional science curricula with direct instruction on the causal structures that underlie scientific phenomena has a statistically significant effect on increasing student achievement in demonstrating understanding of scientific concepts. In order to investigate additional contextual variables that might support the gains in achievement, we conducted a cross-case analysis of classroom discourse from eighth grade classrooms of two teachers who participated in some of the earlier studies mentioned above, using the same density curriculum. Our data was comprised of video footage of demonstrations designed to reveal the underlying mechanisms that cause an object to sink or float in a given liquid. Our analysis centered on the following questions: (1) What types of patterns in the cognitive processes and types of knowledge that are reflected in teacher and student contributions characterize the class discussions? And (2) what differences and similarities do we observe in the patterns that are detected in the two classrooms?

PERSPECTIVES AND THEORETICAL FRAMEWORK

We take a social constructivist approach that views thinking as occurring at the juncture of the appropriation of culture through social interactions and individual contributions to that discourse (Hicks, 1996, p. 107). Therefore, we identified discourse as an effective conduit for studying learning processes in classroom environments. Within this mode of interaction we were interested in tracking the contributions of teachers and students in terms of the cognitive processes and types of knowledge they displayed within learning conditions that we consider as generally effective, based on a previous study of the curriculum. Elsewhere, Perkins and Grotzer (2000; in press) report on the causal intervention used in this study and contrast the success of students with varying degrees of exposure to the causal intervention. This paper builds on those findings and expands that analysis to consider how two different teachers engaged students in the causal discussion components. The current analysis uses classroom discourse from two teachers who were involved in the earlier study of the density curriculum based on causality, and (according to pretest/posttest similarities…etc.) we find no reason to expect that current student achievement would differ greatly from the level that was demonstrated in the previous year.

Therefore, we expected to find general trends in classroom discourse that can be associated with high levels of student understanding for key concepts in density.

The curriculum was developed by Houghton, Grotzer, and Basca (1999) drawing upon earlier work by Smith and colleagues (e.g., Smith et al., 1994; Snir et al., 1989). It was tested and refined over the next four years. The curriculum includes RECAST activities that are designed to reveal the underlying causal structure of a concept to students. For example, one of the RECAST activities in the density unit entails the following:

> …[Students] are first shown a big piece of candle that sinks when it is placed in a clear liquid, and a small piece of candle that floats when it is placed in [another] clear liquid. This outcome fits with most students' expectations. Then the pieces of candle are switched. To the students' surprise, the big piece of candle floats and the small piece of candle sinks. The outcome pushes them beyond a linear, feature-based causality of "the weight makes it sink" or "the density makes it sink" to a relational causality. Students begin to focus on the liquid and the object and realize that the causal pattern is a relationship between greater and lesser density of objects and liquid (Liem, 1981). (Perkins & Grotzer, in press, p. 28).

In addition to fostering understanding of conceptual knowledge generally, the above curriculum was designed to increase student understanding of scientific phenomena at the structural level of knowledge (Grotzer, 2002) by incorporating discussions on causality. Structural knowledge represents the highest level of conceptual knowledge because it includes "knowledge of principles and generalizations together with their interrelationships that present a clear, rounded, and systemic view of a complex phenomenon, problem, or subject matter" (Anderson and Krathwohl, 2001, p. 51). While the overall curricula containing RECAST activities has been demonstrated to be effective through aggregated individual measures of student achievement such as written inventories and interview data (e.g., Grotzer, 2000; Basca & Grotzer, 2001; Grotzer & Basca, 2003; Perkins & Grotzer, 2000, in press), previous studies have not attempted to consider the contribution of class discussions during the RECAST activities in order to suggest how discussions based on these demonstrations reveal student understanding. The current study traces patterns of communication that reveal student understandings and identifies and explains how certain interchanges may affect student understanding.

Using the framework of conceptual blending, one may describe RECAST activities as "very efficient representations and expressions to prompt and guide someone else to develop [knowledge] relatively quickly" (Fauconnier & Turner, 2002, p. 77). The RECAST activities provide discrepant events in which the outcome of a demonstration is unexpected to those who do not have a deep understanding of the phenomenon in question. However, rather than just helping students revise common misunderstandings, they encourage students to attend to the causal structure implicit in a concept and to restructure their understandings to fit with how scientists might structure the concept. They are sensory (often visual) representations of phenomena that "present the effect directly in the cause" (Fauconnier & Turner, 2002, p. 77), thereby allowing the students to experience the underlying mechanism and its effects simultaneously, which encourages global understanding. The demonstration is accompanied by teacher moderated class discussion, which is meant to provide an explicit deconstruction of cause and effect so that students will be able to attribute an underlying causality to the phenomenon. In order to recognize and detect trends among the cognitive levels reflected in teacher and student comments while they deconstruct a RECAST activity, we have chosen to analyze segments of videotape during a demonstration of sinking and floating.

METHODS

Very few techniques have been developed to attribute cognitive processes to statements made during discourse. During the authors' search through the ERIC database for such taxonomies as can be applied to classroom communication and/or discourse analysis, only two such methods were found (excluding studies that labeled metacognitive statements without recognizing other cognitive processes). James Gallagher and colleagues created a methodology for analyzing classroom discourse known as the Topic Classification System (more commonly known as TCS; e.g., Appendix A in Gallagher et al., 1968), which is based loosely on the categories of J. P. Guilford's Structure of the Intellect (Guilford, 1967). However, we found that TCS parses data into such broad groupings that student and teacher comments often occupy the same unit of analysis,[1] which doesn't allow for as finely grained analysis as is needed for studying student and teacher interactions. Another study of classroom discourse (Mills et al., 1980) was able to sort teacher and student comments into two categories: lower and higher cognitive processes, as classified by three different taxonomies: Bloom's Taxonomy (1956), Aschner-Gallager (an earlier version of Gallagher's TCS), and the Smith and Meux Logic of Teaching system. However, the authors of that paper were not explicit on how they classified statements within the taxonomies.

Failing to find a precursor that addressed our objectives in analyzing oral discourse, we created our own taxonomy (see Tables 1 and 2), borrowing much from Anderson and Krathwohl's 2001 revision of Bloom's Taxonomy. In this source we found the separation of types of knowledge (i.e., factual, conceptual, procedural and metacognitive) from the cognitive processes (i.e., remember, understand, apply, analyze, evaluate, and create) particularly insightful in establishing a model of cognitive activity, and useful at the more practical level of applying cognitive science to educational objectives. Anderson and Krathwohl's (2001) characterization of learning objectives as consisting of a verb (the cognitive process the learner will be able to do) and a noun (the type of knowledge the learner will be acting on, with the resulting implication that the learner is the subject of the sentence) is both an accurate representation of the structure of learning objectives, and a useful application of common terminology to clarify the role of cognitive science in shaping instructional goals. We broaden their verb and noun analogy of cognitive processes and knowledge types to describe the general format of what a person reveals about a way in which he or she is able (or unable) to use a given type knowledge when he or she speaks. However, the content of statements used in everyday discourse includes cognitive processes that are more immediate than those which are frequently specified as desired outcomes

[1] For example, a particularly important unit of analysis defined by Gallagher et al. (1968) is the *developed topic*, and "the minimum length for a developed topic is 15 type-written lines or script" (p. 59), which would group many short exchanges among the teacher and students into a single unit of analysis. Other units are similarly large, for example, "Activity…will be divided off when it consumes at least two minutes of class time" (p. 60). Furthermore, the authors do not give their reasoning for choosing these particular criteria (the numbers of type-written lines to classify a topic as *developed*, or the number of minutes of class time that are needed to constitute an *activity*) when defining their units of analysis.

of learning. While the most basic cognitive process in Anderson and Krathwohl's (2001) taxonomy is the retrieval of information from long-term memory, we found that *perception* of elements of one's immediate environment surfaces frequently in classroom discourse. Furthermore, showing a simple awareness of instructional materials such as photographs, diagrams and text as well as dynamic processes such as lab demonstrations and the comments of others reveals a student's focus of attention and is therefore important in its own right. Signifiers of students' perceptions are also noteworthy in educational settings because awareness of objects, actions and /or ideas is a precursor to the more complex cognitive processes.

We therefore added a new category to Anderson and Krathwohl's (2001) taxonomy to accommodate cognitive processes associated with perception. We relied heavily on the description of *observing* within the broader *data gathering* category of a taxonomy created by Hannah & Michaelis (1977) to create the overall category of *perceive* for the cognitive process section of the discourse taxonomy. The two subcategories we developed within the *perceive* category were also informed by the elements of the first three categories of a taxonomy of perception developed by Moore (1970).[2] The perceptual-motor domain presented in Moore (1970) is "characterized by sensory-development activity performed in the presence of a stimulus… Perception is defined as a process of extracting information from the stimulus…elements are ordered on the principle of increasing information extraction" (p. 409). We did not incorporate the fourth and fifth categories, *perception of meaning*, and *perceptive performance*, in Moore's (1970) taxonomy into our *perceive* category because they largely describe composites of perceptive activity with higher cognitive processes. However, the abilities described by Moore's fourth and fifth categories can be described in much more detail by using the other (higher) cognitive process categories in the discourse taxonomy with the understanding that perception is a basic prerequisite to conscious thought,[3] and therefore *perceive* is a necessary first step that underlies all of the other cognitive processes. However, we chose to code a statement using the *perceive* category only when higher cognitive processes were not evident in order to eliminate redundancy and readily distinguish statements that reveal very little about a speaker's immediate thought processes (coded as 0 *perceive*, the lowest category in the cognitive process dimension) from those that show evidence for long term retention of information (coded as 1 *remember*), or evidence for more complex thinking (coded as 2 *understand*, 3 *apply*, 4 *analyze*, 5 *evaluate*, or 6 *create*, as appropriate).

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[2] The first two categories of Moore's (1970) hierarchy, *sensation* and *figure perception*, respectively, are combined to form the more basic of the two subcategories that represent the cognitive process *perceive* in the discourse taxonomy, and Moore's third category, *symbol perception*, constitutes the more complex subcategory.

[3] Perception that underlies conscious thought can be made explicit through deliberate communication (e.g., prefacing an idea or observation with the sensory basis on which it was founded, such as "I saw/heard/felt…", or by referencing the ideas or symbols on which one's own ideas are founded, such as "Based on what you said…." or "Using this formula…."). Alternately, perception can be implicit at the subconscious level, as can be seen in cases of intuitive responses where one cannot specify exactly why he or she has taken a specific action, or where sources of inspiration for an idea are not identified.

Table 1: The Cognitive Process Dimension [by Anderson and Krathwohl (2001), with additions and changes bracketed or footnoted]

CATEGORIES & COGNITIVE PROCESSES	ALTERNATIVE NAMES [4]	DEFINITIONS [5] [FOR USE IN APPLYING CODES TO DATA]
[0. PERCEIVE[6]]	[Sensing, detecting, observing]	[Gathering and reporting information with a minimal amount of processing. Describe data either from first hand sensory experiences or from instructional materials (e.g., reading aloud, describing diagrams).[7] For our purposes, this category refers to description of immediate events (that were experienced in that particular class session). Simple description of events previous to the class should be coded using the Remember category.]
[0.1 PERCEIVING ENTITIES OR PHENOMENA[8]]		[Show awareness of an entity (including a physical, mental or emotional state or attitude) or a phenomenon (change in an entity) through sensory means, e.g., repeating another's words verbatim or acknowledging that something has been said]
[0.2 PERCEIVING SYMBOLS]		[Show awareness of the symbolic representation of an entity or phenomenon, including abstractions that are not directly available to the senses, such as oral language, written text, diagrams, and equations. (Note that this doesn't necessarily mean interpreting the meaning of the symbols or understanding an abstraction, which requires one of the higher cognitive processes—because this taxonomy is being used specifically for educational purposes, we will take into account expectations of prior learning so that if the act of reading is trivial to a student, reading aloud would be considered as 0.2 *perceiving* whereas the same activity would require active and sustained use of higher cognitive processes for a person who is just acquiring literacy skills)]

[4] Alternative names are given to illustrate a broad range of variety within each category and are not meant to be referenced for applying codes to data. See Appendix A for a discussion of how the alternative names relate to the category definitions.
[5] Because each term has multiple meanings, we've included excerpts of the parts of dictionary definitions that apply in order to clarify our intent.
[6] Categories I-III from Moore 1970 are appropriate, but the higher levels are not because they incorporate other cognitive processes from this table. The more basic categories from the Affective Domain (Krathwohl et al, 1964) are also relevant here, as well as *observing* in the Data Gathering category in Hannah and Michaelis (1977).
[7] From *observing* in the Data Gathering category in Hannah and Michaelis (1977).
[8] These two sub-categories, 0.1 and 0.2, have been chosen to record and emphasize how direct an experience the learner has with the educational material (via sensory contact or indirectly through symbols). We chose not to preserve the more subtle distinctions in Moore's (1970) hierarchy that specify one's abilities to differentiate among subtleties within a class of observations, but we acknowledge that such distinctions may be useful for some educational settings.

1. REMEMBER		Retrieve [delete the term "relevant;" issues of relevancy will be coded separately] knowledge from long-term memory
1.1 RECOGNIZING	Identifying	Locating knowledge in long-term memory that is consistent with presented material [e.g., the student chooses an answer from options that are presented]
1.2 RECALLING	Retrieving	Retrieving [delete the term "relevant;" issues of relevancy will be coded separately] knowledge from long-term memory
2. UNDERSTAND		Construct meaning from instructional messages, including oral, written, and graphic communication
2.1 INTERPRETING	Clarifying, paraphrasing, representing, translating	Changing from one form of representation (e.g., numerical) to another (e.g., verbal) [or representing the entity or phenomenon using the same mode of expression without exact precision, but keeping as close to the original as possible. For example, writing a caption for a photograph, rephrasing a person's words with only nuanced changes in meaning]
2.2 EXEMPLIFYING	Illustrating, Instantiating	Finding a specific example or illustration of a concept or principle [or factual or procedural knowledge]
2.3 CLASSIFYING	Categorizing, subsuming	Determining that something belongs to a category (e.g., concept or principle [or factual or procedural knowledge])
2.4 SUMMARIZING	Abstracting, generalizing	Abstracting a general theme or major point(s)
2.5 INFERRING	Concluding, extrapolating, interpolating, predicting	Drawing a logical conclusion from presented information [i.e., within the logic inherent to the system of principles presented to the learner in the immediate context or pertaining to the situation within the learner's experience. Also, this subcategory is different from 2.7 explaining because only the cause or the effect is expressed in 2.5 inferring, while both must be expressed in 2.7 explaining.]
2.6 COMPARING	Contrasting, mapping, matching	Detecting correspondences [including similarities or differences] between two [or more] ideas, objects, [facts, procedures, phenomena] and the like
2.7 EXPLAINING	Constructing models	Constructing a cause-and-effect model of a system [or body of thought. Using general terms (as opposed to 2.2 exemplifying) to communicate an idea or structure, .][9]
3. APPLY		Carry out or use a procedure (sequence of actions) in a given situation
3.1 EXECUTING	Carrying out	Applying a procedure to a familiar task
3.2 IMPLEMENTING	Using	Applying a procedure to an unfamiliar task

[9] Explaining includes focusing on the outer effects of a model to the exclusion of the intricacies of its inner workings; describing both the outer effects or context of the system and how the parts within the system relate to each other would be 4.2 *organizing*, which is often made up of a chain of statements made at the understanding level. Cause and effect are stated without qualification at the 2.7 level of explaining; details about the intricacies within a cause and effect relationship or of the relationship of the cause and effect model to other elements in the system are not given at this level.

4. ANALYZE		Break material into its constituent parts and determine how the parts relate to one another and to an overall structure or purpose [inherent to this is an awareness of the system or context]
4.1 DIFFERENTIATING	Discriminating, distinguishing, focusing, selecting	[Overtly] distinguishing relevant from irrelevant parts or important from unimportant parts of presented material
4.2 ORGANIZING	Finding coherence, integrating, outlining, parsing, structuring	Determining how elements fit or function within a structure
4.3 ATTRIBUTING	Deconstructing	Determine a point of view, bias, values, or intent underlying presented material
5. EVALUATE		Make [value] judgments [e.g., good or bad, right or wrong, useful or useless] based on criteria and standards
5.1 CHECKING	Coordinating, detecting, monitoring, testing	Detecting inconsistencies or fallacies within a process or product; determining whether a process or product has internal consistency; detecting the effectiveness of a procedure as it is being implemented
5.2 CRITIQUING	Judging	Detecting inconsistencies between a product and external criteria, determining whether a product has external consistency; detecting the appropriateness of a procedure for a given problem

6. CREATE		Put elements together to form a coherent or functional whole; reorganize elements into a new pattern or structure [or make a concept, plan or product that is unique compared to others the person has been exposed to. The person may assemble/combine parts that are familiar or generate new ones, but, in the end, the product itself must be unlike others due to either the uniqueness of the combination or generation of new/unique parts within it; the item that has been created is one that is qualitatively different from what has come before (in that person's experience)…[10]]
6.1 GENERATING	[delete Hypothesizing,[11] add Originating[12]]	[to develop an idea that is unlike others in the learner's experience, through means of a logic that goes beyond the system of principles presented to the learner in the immediate context[13] (however, developing an idea using a logic that has been presented to the learner or that has been used in the same situation would be 2.5 inferring)]
6.2 PLANNING	Designing	Devising a procedure for accomplishing some task
6.3 PRODUCING	Constructing	Inventing a product [including a physical product, a theory, etc.; something deemed to be a complete work in and of itself]

[10] This definition of Create recognizes that an interpretation of an existing concept, plan or product can be considered a creation in its own right if it incorporates a sufficient amount of originality, based on criteria relevant to the study being conducted. Therefore, care must be taken when distinguishing between the 2.1 *interpreting* cognitive process and the 6.1, 6.2 and 6.3 Create cognitive processes.

[11] Anderson and Krathwohl's (2001) alternate name for the *generating* 6.1 subcategory of Create is *hypothesizing*, which has several meanings, many of which are associated with cognitive processes that differ widely. For example, Merriam-Webster (1989) defines *hypothesis* as "…a formula derived by inference…." This definition makes *hypothesizing*—the act of creating a hypothesis—a synonym to *inferring* (2.5 in the *understand* category). Random House (1998) defines *hypothesis* as "a mere…guess," and a guess presented without any indicators that would offer insight into the rationale by which it formed would best be categorized in the 0 *perceive* category because it would be a perception based on a subconscious process such as intuition. Another definition of *hypothesis* by Random House (1998) is "a proposition…set forth as an explanation…." If the proposition set forth by a hypothesis offers an original perspective on the issue, it belongs in the 6.1 *generating* category.

[12] *Originate* is defined by Random House (1998) as "…to take its origin or rise; begin; start; arise… to give origin or rise to; initiate; invent…" We've replaced Anderson and Krathwohl's term *hypothesizing* with *originating* because it has fewer definitions and is therefore less ambiguous, and because it better conveys the role originality has in the Create category.

[13] Anderson and Krathwohl's "Coming up with alternative hypotheses based on criteria" was deleted from our definition to eliminate the ambiguity that surrounds the term "hypothesis," mentioned in footnotes above. While not all ambiguity can be eliminated from any definition because different readers will interpret the same phrase in slightly different ways, we hope that our contrast between originality and employing a familiar mode of logic illuminates the aspect of *generating* that we find most salient.

Table 2: The Knowledge Dimension [by Anderson and Krathwohl (2001), with additions and changes bracketed or footnoted]

MAJOR TYPES AND SUBTYPES		**DEFINITIONS**[14] **[AND EXAMPLES]**
A. FACTUAL KNOWLEDGE		The basic elements students must know to be acquainted with a discipline or solve problems in it. "For classification purposes, *Factual knowledge* may be distinguished from *Conceptual knowledge* by virtue of its very specificity; that is, *Factual knowledge* can be isolated as elements or bits of information that are believed to have some value in and of themselves." (Anderson & Krathwohl, 2001, p.45)
A.a. Knowledge of terminology		"knowledge of specific verbal and nonverbal labels and symbols (e.g., words, numerals, signs, pictures)…the basic language of the discipline" (p. 45) [specifically, knowledge of membership or non-membership in the single category that is defined by the given label or symbol (as opposed to knowledge of the criteria for membership in the most appropriate of more than one related category, which would be B.a., because knowledge of related categories would offer some contextualization of the knowledge within a larger structure.)]
A.b. Knowledge of specific details and elements		"knowledge of events, locations, people, dates, sources of information, and the like [specific or approximate information other than terminology] …specific facts are those that can be isolated as separate, discrete elements in contrast to those that can be known only in a larger context." (p. 47)

[14] Because each term has multiple meanings, we've included excerpts of the parts of dictionary definitions that apply in order to clarify our intent.

B. CONCEPTUAL KNOWLEDGE		The interrelationships among the basic elements within a larger structure that enable them to function together
B.a. Knowledge of classifications and categories		"the specific categories, classes, divisions, and arrangements that are used in different subject matters." [A.a. or A.b. with reference to one or more related category or the larger context]
B.b. Knowledge of principles and generalizations		"principles and generalizations…describe the processes and interrelationships among the classifications and categories…[but] the principles and generalizations in subtype Bb do not need to be related in any meaningful way." (pp. 51-52)
B.c. Knowledge of theories, models, and structures		"knowledge of principles and generalizations along with their interrelationships…Bc differs from Bb in its emphasis on a set of principles and generalizations related in some way to form a theory, model, or structure." (pp. 51-52)
C. PROCEDURAL KNOWLEDGE		[Knowledge of how to approach and perform discipline-specific tasks and projects, including using] methods of inquiry, and [a discipline's] criteria for using skills, algorithms, techniques, and methods; [the series of actions a person would make to complete an objective within the regular practices of a given discipline]
C.a. Knowledge of subject-specific skills and algorithms		Knowledge of subject-specific skills and algorithms [that a person would enact or perform]
C.b. Knowledge of subject-specific techniques and methods		Knowledge of subject-specific techniques and methods [knowledge of appropriate flexible use of subject-specific skills and algorithms—flexible use of Ca; knowledge of problem solving tactics specific to the discipline or context]
C.c. Knowledge of criteria for determining when to use appropriate procedures		Knowledge of criteria for determining when to use appropriate procedures [knowledge of criteria for when to use appropriate subject-specific techniques and methods—criteria for using Cb]

D. METACOGNITIVE KNOWLEDGE		Knowledge of [ways one can manage one's thinking] as well as awareness and knowledge of [a particular person or group's preferred mode of thinking or level of] cognition
D.a. [General] Strategic knowledge		[Knowledge of general ways one can acquire needed knowledge or use cognitive processes to achieve a goal; knowledge of broad strategies that are applicable to many disciplines or contexts. For example,] knowledge of outlining as a means of capturing the structure of a unit of subject matter in a textbook, knowledge of the use of heuristics[15]
D.b. Self-knowledge[16]		[Knowledge about a particular person or group's level of awareness or cognitive abilities, aptitudes or preferences, either generally or for a specific situation. Also, indication of a type of knowledge one does or does not know and/or indication of a cognitive process one believes one can or cannot perform. For example, knowledge that representing problems visually by using diagrams is a personal preference for gaining insight into the problem, knowledge that one can perform long division but has trouble working with fractions, knowledge that one doesn't know the definition of a vocabulary word]

Developing the discourse taxonomy was an iterative process in which we began with the revised version of Bloom's Taxonomy (Anderson and Krathwohl, 2001), and attempted to use it to code classroom discourse of lessons from a different science unit than the data used in the study. In addressing weaknesses that had become evident while coding the sample data, we used theory and logic to refine the category and subcategory definitions of the cognitive processes and types of knowledge that comprise the taxonomy, and generated principles for using the taxonomy to code discourse in a manner that was both internally consistent (reliable in subsequent applications by the same researcher as well as yielding the same results for transcripts that had been coded by different researchers) and appropriate to the context (i.e., describing the situation as accurately as possible). Subsequent iterations of this process eventually led to the creation of the discourse taxonomy presented in this paper (Tables 1 and 2), along with a training guide that exemplifies difficult coding decisions and how one would apply the taxonomy definitions to code example statements that exhibit subtle differences (see Appendices A and B). A description of how we dealt with issues of validity while developing this method of coding are addressed in the Validity section that follows the Findings section.

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[15] Merriam-Webster (1989) defines heuristics as…involving or serving as an aid to learning, discovery, or problem-solving by experimental and esp. trial-and-error methods…also: of or relating to exploratory problem-solving techniques that utilize self-educating techniques (as the evaluation of feedback) to improve performance.

[16] We have eliminated one of Anderson and Krathwohl's (2001) subcategories because we found it overlaps with category D.a., Strategic knowledge.

DATA SOURCES

We analyzed approximately 32 minutes of videotape for each of two teachers instructing different mixed-ability classes. Both Ms. Smith and Mr. Johnson[18] used the same lesson plan in which students were asked to make predictions about whether two unopened soda cans (one regular, one diet) would sink or float when placed in an aquarium of water. When the cans were placed in the tank, the diet soda floated while the regular soda sank to the bottom. In one class the students also predicted what would happen to the cans if corn syrup were added to the water, while in the other class students gave suggestions on what they could alter in order to get the regular soda can to float. In both classes the corn syrup was added, which resulted in both cans floating. Class discussion of the entire demonstration ensued.

Although we regularly videotaped a total of six classes taught by these teachers during the fifth year of the UCP study, for this analysis we chose the two classes that were the most evenly matched in pretest scores of understanding of density concepts.[19] Although we were not able to randomly assign students to these classes, we were able match classes for comparison according to pretest scores and gains in achievement (as measured by the difference in each student's pre- and post-test scores). Therefore, characterizing the discourse in the classrooms of these two teachers who have different teaching styles will show two ways of conducting the lesson that are associated with equivalent student outcomes as measured by the students' written inventories.

Pretest scores were nearly identical in the two classes chosen for this study ($\underline{t}$ (df = 41)=-0.021, $\underline{p}$ =0.98, see Table 3 for details).[20] Furthermore, a comparison of the pretest and posttest scores for each student showed that, at the aggregate level, the gains in understanding density concepts were not statistically significant across classrooms (paired $\underline{t}$ (df=38)=-0.332, $\underline{p}$ =0.74). Because equivalent gains in understanding occurred in both classes, it is important to acknowledge that ways in which the teachers led the classroom discourse yielded similar outcomes in under- standing. Therefore, we expressly cannot conclude from the results of this study that the pedagogy and overall classroom management techniques of either teacher is to be preferred in

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[17] A second coder randomly selected four two-minute segments from each teacher's class, for a total of 25% of the data. After coding half of these segments, the researcher looked for trends in mismatches among the two sets of codes, and clarified any coding rules or definitions that were not consistently being used by the second coder. The data from the study was not referenced in this discussion; examples of coding strategies were given in science topics other than density. After the discussion, the second coder recoded the data she had chosen from the first half of the classes, then coded randomly selected sections from the second half of the lesson. The first coder recoded the entire dataset with the newer examples in mind to make sure that the subtleties that were made explicit in the discussion were applied systematically to all of the data.

[18] Pseudonyms have been used for all teachers and students participating in this study.

[19] The equivalency of initial ability and gains in understanding were determined by pretest scores of the understanding of the causal mechanisms associated with density through essay answers accompanied by illustrated models of the phenomena of interest, and multiple choice questions designed to reveal understanding of more general concepts related to density. The same test was administered before and after the unit for optimal reliability between the measures. Scoring was blind to the six classes comprising the larger study, as well as pre- versus posttest. Retest issues are not a concern in misconceptions research because conceptual change is notoriously hard to achieve and students tend to say the same things before and after instruction. Also, the work that we did with controls in the early phases of the project showed no significant conceptual change beyond the typical points of difficulty from pre- to post-test (Grotzer 1999, 2000).

[20] An alpha-level of 0.05 was used for all analyses presented in this paper.

terms of benefits, as measured by the assessments used in the larger study, to student understanding of the density curriculum.

Table 3: Comparison of Density Pretest and Gain Scores for Ms. Smith and Mr. Johnson's Classes.

	Pretest			Gain		
Class	mean	standard deviation	t-test	mean	standard deviation	paired t-test
Ms. Smith (n=20)	18.35	4.87	t=-0.021 (p=0.98)	12.46	7.06	t=-0.332 (p=0.74)
Mr. Johnson (n=23)	18.32	5.03		11.77	6.03	

Note: n=19 and n=21, respectively, for the gain scores in Ms. Smith and Mr. Johnson's classes. Some students were absent on the day the posttest was administered, and we were unable to collect posttests from three students before the subsequent unit had begun. The density unit was followed by a unit on pressure, which reinforced many of the concepts concerning causal structures previously covered. To make sure the absentees did not have the advantage of drawing upon these related lessons, we did not obtain posttest scores after the new unit had begun. The distribution of pretest scores was rather bell-shaped and symmetric for both classes, while the distribution of gains was bell-shaped and symmetric in Mr. Johnson's class, but slightly skewed with a tail in the lower values for Ms. Smith's class.

FINDINGS

When interpreting the findings, it is important to note that as it is used here, the system for classifying cognitive processes and student responses does not imply a hierarchy among the categories as is often implied elsewhere (Andersen and Krathwohl, 2001). Instead, factual knowledge is characterized as often being more basic than conceptual or procedural knowledge (and some types of metacognitive knowledge), but otherwise the knowledge types are not considered to be ordered by complexity. Similarly, we generally consider perceiving and remembering to be the two most basic cognitive processes in that they are a prerequisite for the others, but we do not consider, for example, understanding knowledge to be a necessarily more complex task than applying knowledge.

We found that while each teacher showed a preference for certain cueing patterns, both teachers elicited student responses that demonstrated both basic and higher order cognitive processes. In addition, we found that the mode of student responses sometimes followed that of the preceding prompt, and sometimes were quite varied according to both the dimensions of cognitive processes and knowledge types, particularly when the responses followed prompts for higher order combinations of cognitive processes and knowledge types. It is also important to preface these findings with the caution that, due to the nature of these data, we were unable to determine whether such cueing initiated an understanding of conceptual knowledge in responding students or only encouraged these students to respond in ways that displayed this particular combination of cognitive process and type of knowledge. However, drawing such a distinction is not necessary for the purposes of using these cues to conduct formative assessment. Regardless of how the student had come to his or her understanding of the concept matter, he or she has made that understanding visible in response to the teacher prompt.

In characterizing the cognitive processes and knowledge types that most frequently appeared in the utterances during the classroom discourse of this lesson on density, we can see some overall trends (see Tables 4 and 5). In both classrooms, topics of the discourse ranged across all four knowledge types, with factual knowledge occurring most frequently in student and teacher utterances (68.5% and 58.0% of all utterances in Ms. Smith and Mr. Johnson's classes, respectively). During this lesson, both classes also made statements or asked questions that accessed categories 0-3 (perceiving, remembering, understanding, and applying) of the cognitive processes regularly, while rarely calling upon other cognitive processes such as analyzing, evaluating and creating. In both classes, more than 50% of the utterances during the lesson belonged to only two combinations of cognitive process and knowledge types: perceiving factual knowledge (0A), and understanding factual knowledge (2A). This result is not particularly surprising, considering that the RECAST activity was a demonstration in which students were asked to first predict the outcome of each step in the demonstration (understanding factual knowledge, 2A). For example, Ms. Smith asked her class, "…predict before I do it…what I want you to figure is what do you think's gonna happen when I place these in the tank [2A]." The teachers and students would also make direct observations of what was happening before their eyes (perceiving factual knowledge, 0A). For example, Mr. Johnson announced the result of the first stage in the demonstration, after a student had placed the first can in the tank of water: "Okay so we have—the Diet Coke can floats [0A]." After the second can was added to the tank, a student in Mr. Johnson's class noted "It sinks! [0A]" We might consider the bulk of the statements made in these categories as laying the foundation for understanding conceptual knowledge (2B). An example of understanding conceptual knowledge from Ms. Smith's class involves the following exchange (the cognitive process and knowledge type codes are included to show which of the student's statements might be considered as revealing conceptual knowledge versus factual knowledge):

Carla: I think they'll both float. [2A]
Ms. Smith: Why? [2B]
Carla: I just do. [0A]
Ms. Smith: But what would make something float? Wh— [2B]
Carla: If it's less dense than the water? [2B]

Understanding conceptual knowledge such as the above example occurred less frequently than statements of perceiving factual knowledge or understanding factual knowledge within this lesson. Nevertheless, understanding conceptual knowledge was demonstrated uniformly in classroom gains according to paired t-tests of gains from a pretest at the beginning of the unit to a post-test that was conducted after the unit[21] (this is the final lesson on density before transitioning to the topics of pressure and heat and temperature). It should also be noted that these three combinations of cognitive process and knowledge type (0A, 2A, and 2B) are among six that occurred the most frequently in both classes.

[21] In the previous (fourth) year of the study, classes using this curriculum (also taught by these teachers at the same school) also showed large gains in understanding over the course of the unit. Furthermore, the gains for the groups using this curriculum for both the fourth and fifth years of the study were statistically significantly higher than those in a control group of similar students taught by the same teachers in the fourth year of the study, using an alpha-level of 0.05 (Grotzer, 2005).

Table 4: Ms. Smith's class discussion, types of utterances by all speakers during the lesson

# %	Cognitive Process							Totals
Knowledge Type	0 perceiving	1 remembering	2 understanding	3 applying	4 analyzing	5 evaluating	6 creating	
A factual	86 23.8%	37 10.2%	122 33.7%	3 0.8%	0 0.0%	0 0.0%	0 0.0%	248 68.5%
B conceptual	0 0.0%	4 1.1%	57 15.7%	0 0.0%	2 0.6%	0 0.0%	0 0.0%	63 17.4%
C procedural	1 0.0%	1 0.0%	5 1.4%	24 6.6%	0 0.0%	0 0.0%	0 0.0%	31 8.6%
D metacognitive	19 5.2%	1 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	20 5.5%
Totals	106 29.3%	43 11.9%	184 50.8%	27 7.5%	2 0.6%	0 0.0%	0 0.0%	362 100.0%

Table 5: Mr. Johnson's class discussion, types of utterances by all speakers during the lesson

# %	Cognitive Process							Totals
Knowledge Type	0 perceiving	1 remembering	2 understanding	3 applying	4 analyzing	5 evaluating	6 creating	
A factual	152 31.1%	23 4.7%	108 22.1%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	283 58.0%
B conceptual	5 1.0%	4 0.8%	45 9.2%	0 0.0%	4 0.8%	0 0.0%	0 0.0%	58 11.9%
C procedural	16 3.3%	5 1.0%	6 1.2%	86 17.6%	0 0.0%	1 0.2%	0 0.0%	114 23.4%
D metacognitive	27 5.5%	2 0.4%	3 0.6%	0 0.0%	0 0.0%	1 0.2%	0 0.0%	33 6.8%
Totals	200 41.0%	34 7.0%	162 33.2%	86 17.6%	4 0.8%	2 0.4%	0 0.0%	488 100.0%

While there were many similarities between the two classes in overall discourse trends, there were also some notable differences. For example, there were 362 codable[22] utterances in Ms. Smith's class, while there were 488 in Mr. Johnson's class. Given that 32 minutes of videotape were analyzed for each class, such a disparity illustrates the different ways in which the teachers conducted their classrooms. The statements made in Ms. Smith's class (by both the teacher and students) were longer, and only one person would speak at a time. Ms. Smith would ask students to raise their hands to be called upon in turn, sometimes asking students to reference longer explanations they had written during class time or for homework. However, statements made in Mr. Johnson's class were much more brief; Mr. Johnson would often ask a question of the students, and once one student had responded, others would respond to either the initial question posed by the teacher or to another student's statement. At times Mr. Johnson moderated the

[22] Codable utterances were those which were audible (or visible, if nodding or shaking one's head) that contained enough information for us to attach a code to them. Some incomplete statements and chatter about topics that were completely irrelevant to the science class were left uncoded in the interest of accurately reflecting the discourse in which the students were exposed to the subject matter and demonstrated their knowledge of it.

discussion by calling upon students in turn, and at other times students would speak up without being called upon for several conversation turns. In this way, Mr. Johnson's class was more fast-paced; during the less-structured parts of the discourse, students tended to keep their statements brief, sometimes talking over one another. They tended to expound upon their ideas in more detail only when Mr. Johnson called on them directly to repeat their ideas, thereby refocusing the discussion on the individual and providing a more structured environment in which the speaker was less likely to be interrupted.

Table 6: Most frequent combinations of cognitive process and knowledge types for this lesson in utterances per class, rank-ordered by frequency

Ms. Smith's Class			Mr. Johnson's Class		
Combination	Description	% of total discourse	Combination	Description	% of total discourse
2A	understanding factual knowledge	34	0A	perceiving factual knowledge	31
0A	perceiving factual knowledge	24	2A	understanding factual knowledge	22
2B	understanding conceptual knowledge	16	3C	applying procedural knowledge	18
1A	remembering factual knowledge	10	2B	understanding conceptual knowledge	9
3C	applying procedural knowledge	7	0D	perceiving metacognitive knowledge	6
0D	perceiving metacognitive knowledge	5	1A	remembering factual knowledge	5

Another major difference that these characterizations of discourse reveal in Ms. Smith and Mr. Johnson's classes is their emphasis on different aspects of the lesson. For example, the third most frequent combination of cognitive process and knowledge type in Ms. Smith's class is understanding conceptual knowledge (2B). This is largely due to her more strict adherence to the lesson plan, which contains several prompts for the students, such as to explain why the Diet Coke can floated in the tank while the Coke can sank. For example, Ms. Smith not only asked her students to predict what each can would do when it was placed in the tank, but to give their reasoning for why a certain result would occur:

Ms. Smith: All right, uh, does anybody else have another idea about what they will do, different than what people said [2A], or different reasons—like a different thought on what will happen? [2B]

Jason: Well, they're both gonna sink because they already have water in them, and then more ingredients added to the water. [2B]

When asking students these questions, Ms. Smith tended to take several conversation turns with each student who was called upon, following up on the student reply by asking more specific questions, which would often either be followed by an answer at the 2B level by the student who had initially replied, or the last unanswered question would be redirected to be answered by another volunteer in the class. For example, the following excerpt shows how Ms. Smith would follow up on students' responses to probe for answers that demonstrated understanding conceptual knowledge:

Ms. Smith: (nodding head in response to another student's response) Okay – So, Mark. To help him out, and everybody else, what are the two things you need to know when you're thinking about whether something sinks or floats? [2B]

Mark: The ingredients? [1A]

Ms. Smith: Yeah (trailing off). But in general, even if I – say I just had a little rubber duck and I had something else – a pencil. [2B]

Mark: The mass of it? [1A]

Ms. Smith: The mass of it. Okay, keep going guys – what do you need to know, which is the answer to question number 2, listen carefully though, the question number 2, what about the density of the object (touching Coke can) and the density of the water (touching tank of water), do you need to know, Amanda? You had your hand up? [1B]

Amanda: Um, if it – the density I mean? [incomplete]

Ms. Smith: What about it? [2B]

Amanda: If it's more or less than the water. [2B]

Ms. Smith and her class discussed their understanding of the conceptual knowledge that underpinned the classroom demonstration almost twice as much as they discussed the nuts and bolts of how the experiment worked (16% and 7% of the overall utterances, respectively).

On the other hand, Mr. Johnson's class tended to focus on the concrete aspects of the RECAST activity and actions one could take to modify the experiment with twice as much frequency (applying procedural knowledge comprised 18% of the utterances) as the conceptual underpinnings that would explain why the demonstration worked the way it did (9% of the utterances were classified as understanding conceptual knowledge). Given that both classes exhibited the same average gains in understanding conceptual knowledge pertaining to density, it is likely that conversations at the 2B and 3C level both contributed to students' high scores on the posttests. Excerpts of several exchanges at these levels in both classrooms will be given to illustrate these trends.

It is important to note that while we can't say for certain which types of activities contributed most toward student understanding of density concepts, most of their exposure to the course material, as well as feedback on their ideas, occurred during class rather than through homework assignments. While the RECAST activity analyzed in this study is typical of lessons in this curriculum, other types of lessons that involve model-building to explain the phenomena witnessed during RECAST activities are also designed to encourage higher order thinking, and those types of lessons are also likely to support understanding of conceptual knowledge. Further analyses of this lesson's discourse focusing solely on teacher prompts and student responses supports the hypothesis that conversations at the understanding conceptual knowledge (2B) and applying procedural knowledge (3C) levels are associated with the high gains the students exhibited in their understanding of conceptual knowledge in the written inventories. It is likely that other types of lessons in this curriculum also support understanding conceptual knowledge through dialogue that involves both analyzing and evaluating factual, conceptual and procedural knowledge. Analyzing videotape of classroom discussions for a lesson centered on model-building and group critiques of these models would be worthwhile to illustrate how such conversations support student learning. Another promising direction for future studies would be to combine a cognitive analysis of the classroom discourse with interviews conducted before and after instruction from a number of students in each class to determine how the class dynamics might have affected student learning in ways that written inventories are not able to capture.

Trends in teacher prompts and student responses

Ms. Smith prompted her students 164 times during the 32 minutes of discourse that were analyzed, and students responded a total of 127 times (see Tables 7 and 8). In keeping with the finding that identified talk at the level of understanding factual knowledge (2A) as the single most frequent type of utterance in Ms. Smith's class, we find that not only did Ms. Smith prompt for this type of utterance the most frequently (38% of her prompts were in this category), but it was also the most frequent type of response that students gave during the lesson (35% of student responses). It is also important to note that Ms. Smith gave 62 prompts of this type during the 32 minutes of discourse that were analyzed, but only 45 of the student responses belonged to this category. There are two main reasons for this type of disparity. Sometimes the teacher would give a prompt that was not followed by many hands raised in response, and sometimes, in turn-taking with a student, she would give a prompt that would not immediately elicit an answer from that student. In both of those cases, she often rephrased the question (which would yield two prompts on the same topic) or sometimes asked an easier question (such as changing from a prompt at the understanding factual knowledge or conceptual knowledge level to one at the perceiving or remembering factual knowledge level). When an easier prompt followed a more difficult one, students often replied in a combination of cognitive process and knowledge type that matched the latter prompt. Another reason that there are more teacher prompts in the understanding factual knowledge category than there are student responses is because students did not always reply in the same mode as the question that was asked. A more detailed analysis of trends in student responses that don't match the teacher prompts will be forthcoming.

The current analyses show that while higher order prompts sometimes elicited higher order responses and sometimes elicited more basic responses, the teachers' more basic questions were rarely met with responses that exhibited more complex thinking, a trend that one might expect in the discourse of eighth grade classrooms. For example, in response to prompts of understanding factual knowledge, students sometimes answered at a more basic level (perceiving or remembering factual knowledge, rather than understanding or applying). The above exchange among Ms. Smith, Mark and Amanda is an example of this phenomenon, where Ms. Smith prompts the students at the understanding conceptual knowledge (2B) level, and students sustain exchanges of dialogue at more basic cognitive levels before replying at the level of the original prompt. In these types of exchanges, the teacher scaffolds the students by asking key questions that, when answered in succession, often lead the students toward an answer (or a chain of answers) that explicitly would take into account the complexity of the topic being discussed. The exchange between Ms. Smith and Carla at the beginning of the Findings section also exemplifies how a teacher can, through a few additional prompts, scaffold a student to answer the original, more difficult prompt.

Table 7: Teacher prompts for Ms. Smith's class during the lesson

# %	Cognitive Process							Totals
Knowledge Type	0 perceiving	1 remembering	2 understanding	3 applying	4 analyzing	5 evaluating	6 creating	
A factual	29 17.7%	11 6.7%	62 37.8%	2 1.2%	0 0.0%	0 0.0%	0 0.0%	104 63.4%
B conceptual	0 0.0%	2 1.2%	36 22.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	38 23.2%
C procedural	0 0.0%	0 0.0%	2 1.2%	5 3.0%	0 0.0%	0 0.0%	0 0.0%	7 4.3%
D metacognitive	14 8.5%	1 0.6%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	15 9.1%
Totals	43 26.2%	14 8.5%	100 61.0%	7 4.3%	0 0.0%	0 0.0%	0 0.0%	164 100.0%

Table 8: Student responses for Ms. Smith's class during the lesson

# %	Cognitive Process							Totals
Knowledge Type	0 perceiving	1 remembering	2 understanding	3 applying	4 analyzing	5 evaluating	6 creating	
A factual	33 26.0%	20 15.7%	45 35.4%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	98 77.2%
B conceptual	0 0.0%	2 1.6%	16 12.6%	0 0.0%	2 1.6%	0 0.0%	0 0.0%	20 15.7%
C procedural	0 0.0%	0 0.0%	2 1.6%	4 3.1%	0 0.0%	0 0.0%	0 0.0%	6 4.7%
D metacognitive	3 2.4%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	3 2.4%
Totals	36 28.3%	22 17.3%	63 49.6%	4 3.1%	2 1.6%	0 0.0%	0 0.0%	127 100.0%

The two most frequent types of teacher prompts, those for understanding factual knowledge (2A) and for understanding conceptual knowledge (2B) show that Ms. Smith was sticking closely to the lesson plan. The following are examples of prompts suggested in the lesson plan (Houghton, Grotzer, and Basca (1999, 95-96):

1. What do you think will happen when the diet and regular soda cans are placed in the water? [2A]
2. How does the density of something that will sink compare to that of the fluid surrounding it? ….[2B]
6. What do you think will happen when we add corn syrup to the water? Why? [2A followed by 2B]
7. What happened in terms of the relationship between the water and the can of regular soda? Why? [2A followed by 2B]

Similar to the lesson plan, most of Ms. Smith's prompts at the 2A level asked for predictions of what would happen next in the experiment. It appears that students were willing and/or able to reply at this level as well; 38% of the prompts were of this type, and 35% of the student responses were of this type. However, the second-most frequent type of prompt, understanding conceptual knowledge (2B, 22% of prompts) were less likely to elicit responses of this type (13% of student responses were at this level, the fourth most frequent response level). This may be due to the more complex nature of these prompts—these are the "why" types of questions that students may find more difficult to answer. The above exchange between Ms. Smith, Mark and Amanda illustrates how a teacher may need to rephrase a difficult question and explicitly reference different facets of the topic to give multiple opportunities for students to reveal their understanding.

Conversely, teacher prompts at the perceiving factual knowledge level were less frequent in Ms. Smith's class (0A, 18%). These prompts were for the most basic types of observations. An example would be just after Ms. Smith added corn syrup to the water. She asked, "What would you say is going on with them?" A student answered, "They're both floating." However, there were more student responses at this basic level than teacher prompts (0A, 26% responses). This is due to student willingness to volunteer an answer to such prompts as well as students answering other prompts at more basic levels, as we have seen in examples above. We similarly find that student responses in the remembering factual knowledge category exceeded the prompts of this type (16% responses, 7% prompts).

Mr. Johnson's class had some trends that were similar to Ms. Smith's class (see tables 9 and 10). For example, the most frequent type of prompt was at the understanding factual knowledge level (25%), and students frequently replied in kind (25% responses). While 22% of Mr. Johnson's prompts were at the perceiving factual knowledge level, a larger proportion of student responses were at this level (29%). This trend of eliciting more responses at this level than was prompted for is similar to Ms. Smith's class, but note that this type of exchange constitutes a larger proportion of the dialogue in Mr. Johnson's class.

Table 9: Teacher prompts for Mr. Johnson's class during the lesson

# %	Cognitive Process							Totals
Knowledge Type	0 perceiving	1 remembering	2 understanding	3 applying	4 analyzing	5 evaluating	6 creating	
A	22	9	25	0	0	0	0	56
factual	22.0%	9.0%	25.0%	0.0%	0.0%	0.0%	0.0%	56.0%
B	0	0	14	0	0	0	0	14
conceptual	0.0%	0.0%	14.0%	0.0%	0.0%	0.0%	0.0%	14.0%
C	2	0	0	22	0	0	0	24
procedural	2.0%	0.0%	0.0%	22.0%	0.0%	0.0%	0.0%	24.0%
D	6	0	0	0	0	0	0	6
metacognitive	6.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.0%
	30	9	39	22	0	0	0	100
Totals	30.0%	9.0%	39.0%	22.0%	0.0%	0.0%	0.0%	100.0%

Table 10: Student responses for Mr. Johnson's class during the lesson

# % Knowledge Type	Cognitive Process 0 perceiving	1 remembering	2 understanding	3 applying	4 analyzing	5 evaluating	6 creating	Totals
A	73	7	62	0	0	0	0	142
factual	28.9%	2.8%	24.5%	0.0%	0.0%	0.0%	0.0%	56.1%
B	5	4	25	0	3	0	0	37
conceptual	2.0%	1.6%	9.9%	0.0%	1.2%	0.0%	0.0%	14.6%
C	11	3	5	39	0	0	0	58
procedural	4.3%	1.2%	2.0%	15.4%	0.0%	0.0%	0.0%	22.9%
D	15	0	1	0	0	0	0	16
metacognitive	5.9%	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	6.3%
	104	14	93	39	3	0	0	253
Totals	41.1%	5.5%	36.8%	15.4%	1.2%	0.0%	0.0%	100.0%

A major difference between Mr. Johnson's and Ms. Smith's classes is that while Ms. Smith frequently prompted for understanding of conceptual knowledge by asking "why" questions (22% prompts, 13% responses), Mr. Johnson more frequently prompted for applying procedural knowledge (22%) and received student responses at this level (15%) more frequently than at the understanding conceptual knowledge level (14% prompts, 10% responses). If we consider understanding and applying as being more complex than perceiving and remembering, then it appears that Mr. Johnson used a different technique to stimulate discussion about the RECAST activity at deeper levels. Mr. Johnson prompted students to suggest modifications to the experiment to change the outcome. These prompts were at the level of applying procedural knowledge (3C). Like Ms. Smith's prompts for understanding conceptual knowledge (2B), sometimes Mr. Johnson's more difficult prompts needed to be rephrased for the students to be able to answer in kind:

Mr. Johnson: Who hasn't said anything in this class?...Carl, you haven't said anything. And Dave. Can the two of you design something that will get that can to float?….[3C]
Carl: What do you mean by like—[2A]
Dave: —design something? [2A]
Carl: Yeah. [0A]
Mr. Johnson: I have some stuff in the room that I could maybe provide to you that you could do something to this to get that can to float. What—can you come up with some ideas? Or, just how to do it. How—what would you have to do? [3C]
Carl: Like add something to it. [3C]
Mr. Johnson: 'Kay, when you say add something to it, what is 'it'? [2A]
Carl: Like something less de—less dense and like put it on the can or something. [2A]
Mr. Johnson: So if you can attach something to the can to make it less dense somehow that would be a possibility….[2A]

As we can see, the students directly asked Mr. Johnson to interpret his prompt, and Mr. Johnson continued to prompt them at a more basic level (2A) until they had not only responded at the level of his initial prompt (3C), but had clarified their answer to better illustrate their thinking.

In another example that shows how discussion at the applying procedural knowledge level can stimulate deeper thinking about the RECAST activity, discussion of ways to modify the experiment led directly to a discussion focused on understanding the conceptual underpinnings of the phenomenon of sinking and floating. Later in the discussion, a student in Mr. Johnson's class suggested a change to the setup that she thought would make the Coke float (it was currently sitting at the bottom of the tank of water). Her contribution was of the same type as Mr. Johnson's initial prompt (3C, applying procedural knowledge), but it revealed a misconception that another student responded to in terms of understanding conceptual knowledge (2B).

Rachel: You can get a really good container and just keep on pouring water, to make the density of the water more than the density of the Coke can. [3C]
Samantha: But wouldn't it not change it because the volume changes too? [2B]
Jim: Yeah. [0 B]
Rachel: Well, both the mass and the volume (voice trails off) [2 A]
Samantha: So they both increase. [2 A]
Rachel: Right. [0A]
Samantha: So they both stay the same. [2B]
Rachel: Yeah but it's more, it's more than—the Coke can. Like if the—the mass (voice trails off) [2B]
Samantha: The density's gonna stay one though. [2B]
Students: (overlapping) Yeah. [0 A]
Rachel: Okay, I'm confused then. [0D]

In the above exchange, not only did Mr. Johnson's initial prompt to modify the experiment result in revealing a student's misconception about how volume relates to density, but another student's reaction to this misunderstanding brought the discussion back to the central focus of the lesson, which is understanding conceptual knowledge of density.

Later in the class, after students had suggested adding substances (such as salt) to make the water more dense to get the Coke can to float, Mr. Johnson again prompted students to modify the experiment (3C):

Mr. Johnson: …How can you make the Diet Coke can sink in water? What would you do to make it sink? And this is—you guys should know the answer to this cause we actually talked about some of this—can anybody think? John? [3C]
John: Add alcohol. [3C]
Mr. Johnson: Add alcohol. Cause alcohol's what? [1B]
John: Point 8. [1B]
Mr. Johnson: Point 8, and it would make the water less dense, and then the can would—the diet coke can would be more dense and it would sink. [2B]

In the above exchange, a student likely recalls and makes inferences based on a previous RECAST activity in which two different sized pieces of a candle were made to float or sink when placed in two different beakers of clear liquid. During the course of the activity, the students learned that container in which the candle pieces consistently sank was filled with rubbing alcohol, which has a density of .8 or .9 grams/cm^3, and the one in which they consistently floated was filled with water, which has a density of 1 g/cm^3. Notice in this exchange that Mr. Johnson summarizes John's contributions to the discussion in a way that emphasizes understanding conceptual knowledge (2B), even though neither the initial prompt nor the subsequent responses were at this level. This is another way in which Mr. Johnson scaffolded his class to think at the understanding conceptual knowledge (2B) level by means of discussing ways they could modify the experiment (3C, applying procedural knowledge).

It appears that both classes provided opportunity for students to demonstrate connections with the subject at a basic level through frequent prompts of perceiving factual knowledge and remembering factual knowledge (27.7% of prompts, 36.7% of responses at these two combinations of cognitive processes and knowledge types, averaged over both classes). However, a larger proportion of the discussion was filled with prompts for more sophisticated levels of cognition; understanding factual knowledge, understanding conceptual knowledge, and applying procedural knowledge (41.3% prompts, 33.6% of responses at these three combinations of cognitive process and knowledge type, averaged over both classes). Notice that student responses at more complex levels of cognition were slightly less frequent than responses at more basic levels, even though there were many more prompts for students to demonstrate higher order cognitive processes. Students were given ample encouragement to demonstrate their knowledge (or lack thereof) at these higher levels. Students responded in a number of ways to these more difficult prompts. Some responses matched the level of the initial prompt, and demonstrated understandings that were scientifically accurate. Other higher order prompts were met with responses at the same level of cognition that demonstrated misunderstandings, brief silence, or responses at more basic cognitive levels. All four of these types of responses allowed teachers to formatively assess student mastery of the subject matter, and therefore guide the discussion to address misunderstandings during the lesson. Frequent talk at these levels not only provided students a chance to receive feedback on their thinking, but also provided listening students with information at this level.

The most frequent types of prompts and responses in these discussions are not surprising, given the particular learning goals of this lesson. It is important to note that, while the lesson investigated in this study represents a number of RECAST activities that are central to the density unit, other types of lessons are also included in the curriculum. Often, follow-up lessons to RECAST activities centered on model building, in which students illustrate and explain their models for why a certain outcome occurred. Students engaged in analyzing models, evaluating them against the available evidence, and critiquing their explanatory power. These activities necessarily engaged them in demonstrating an understanding of conceptual knowledge (2B), as well as analyzing (4) and evaluating (5) factual and conceptual knowledge, two cognitive processes that were not prominent in the lesson we studied. A promising follow-up to the present analysis might be to use the same investigative techniques on another type of lesson in this curriculum.

VALIDITY

External Validity

First, we made sure the coding system could accommodate all relevant aspects of the data. For this reason, we added the new category of *perceive* to the taxonomy in order to distinguish immediate perceptions from long-term memory. We also marked data that could not be adequately described by the system as not able to be coded (e.g., "x" for inaudible, incomplete or ambiguous statements).

Second, we made sure the assigned codes described the processes that underlie the data. We did this in three ways: (1) we took care to look beyond the surface features of a statement when assigning codes. For example, statements prefaced with "I think…" do not necessarily mean the person is *perceiving their level of cognition* (0.1 D), but such a phrase could preface any combination of cognitive process and knowledge type, such as: "I think I saw the balloon shrink" (0.1 A, *perceive factual knowledge*), "I think we should light the Bunsen burner next" (3.2 C, *execute procedural knowledge*), or "I think the balloon shrank because the pressure surrounding it had changed" (2.7 B, *understand conceptual knowledge*). (2) We took the context of each statement into account when coding the data, including: (a) prior knowledge via curriculum already covered, (b) previous statements in the same conversation that were referenced by the speaker (especially when determining the referents for pronouns), (c) actions that either accompany speech or substitute for it (including demonstrating experiments, nodding one's head, pointing, etc.), and (d) tone of voice (when the wording of a statement could signify more than one meaning). (3) We distinguished between claims of knowledge and actual performances that demonstrate one's cognitive ability and knowledge level (or lack thereof, e.g., by coding claims of knowledge such as "I don't understand how pressure works" as 0.1 D *perceive metacognitive knowledge*, and "The pressure in the bell jar decreased, so the balloon expanded" as 2.7 B *understand conceptual knowledge*.

Internal Validity

As much as possible, we made sure each cognitive process and knowledge category was distinct from the others. We did this by using the core definitions of the categories for assigning codes to statements, not the peripheral definitions that are determined by the various interpretations of the category descriptors (see Appendix A, Figures 1 and 2 for details). We also refined Anderson and Krathwohl's (2001) category definitions to eliminate areas of ambiguity.

For situations that could be appropriately coded in more than one category, we created a set of priorities for dealing with coding conflicts. First, if a statement clearly exhibits two different cognitive processes (i.e., it satisfies the core definition of more than one cognitive process category), we chose the code that best described the complexity of the statement, keeping in mind that the higher order cognitive processes contain simpler cognitive processes. For example, *understand* is a prerequisite for *analyze,* and *perceive* is a prerequisite for all of the other processes. Second, we read through all statements that contain multiple codes to see if they might have been better described by a single code that takes into account all of the simpler processes. For example, an opinion (*0.1 perceive*; "I like …") followed by criteria on which it is based (*0.2 perceive*; "…your diagram. It has labels and shows only the relevant forces in the system.") should be coded as 5.2 B *evaluate conceptual knowledge* instead of 0.1 A *perceive factual knowledge* followed by 0.2 A *perceive factual knowledge*).

One researcher used the abovementioned methods to code all of the data, and it was these codes that were used to generate the findings. This strategy was used to make sure that the codes were applied in as consistent a manner as possible. However, inter-coder agreement was calculated in order to determine that the newly developed coding system would be applied to the data in relatively the same manner by more than one researcher. Although we coded the data using subcategories for cognitive process codes for increased precision (such as 2.6 *comparing*, 2.7 *explaining*, etc.), we computed all reliability estimates at the broader category level (such as 2 *understand*) because that is the level at which our analyses were conducted. The reliability suggested that the scoring method was sufficiently reliable[23] across coders for cognitive processes (Cohen's kappa = .68, percentage agreement= 78%).[24] The reliability for knowledge type codes was slightly lower (Cohen's kappa= .45, percentage agreement =76%.) While the percentage agreement for the application of knowledge type codes was within an acceptable range for exploratory studies (Lombard, Snyder-Duch and Bracken 2002), the lower Cohen's kappa was obtained for two primary reasons. The more easily remedied of the problems appears to be a training issue. The second coder refrained from using the code for metacognitive knowledge (preferentially using the code for factual knowledge instead) due to an unclear understanding of the definitions in the taxonomy table. However, this was easily remedied after the independent coding session with more detailed discussion of the category definition and examples of how the code might be appropriately applied.

The other reason that the knowledge types had a lower reliability estimate is less easily remedied, and mostly involved crossovers among factual knowledge and conceptual knowledge. It is inherently difficult to apply codes to discourse, where a participant's brief statement may not be followed up with probes to better clarify the intended meaning, as would be expected for interview data. An example of a segment of the discourse where the knowledge type that the student is demonstrating is ambiguous is included below:

Ms. Smith: What did you write for question number 4—is what causes the object to remain sunk on the bottom? Why didn't it—why didn't it travel around? Mark, what did you write? I see you have the answer.
Mark: The object's density is um, more than the water.

If one has reason to believe that the student fully understands the definition of the term "density," one would classify his statement as demonstrating conceptual knowledge. However,

[23] Fleiss (1981) concludes that a Cohen's kappa between .40 and .60 indicates fair reliability levels, and between .60 and .75 indicates a good level of reliability.
[24] A second coder randomly selected four two-minute segments from each teacher's class, for a total of 25% of the data. After coding half of these segments, the researcher looked for trends in mismatches among the two sets of codes, and clarified any coding rules or definitions that were not consistently being used by the second coder. The data from the study was not referenced in this discussion; examples of coding strategies were given in science topics other than density. After the discussion, the second coder recoded the data she had chosen from the first half of the classes, then coded randomly selected sections from the second half of the lesson. The first coder recoded the entire dataset with the newer examples in mind to make sure that the subtleties that were made explicit in the discussion were applied systematically to all of the data.

if one does not credit him for understanding the meaning of "density" and instead views his references to it as a token use, one would classify his statements as demonstrating factual knowledge. (Note that the cognitive process that Mark's statement demonstrates was independently coded by both coders as 2.6 *comparing*, which belongs to the *understand* category, regardless of which knowledge type was indicated.)

While the above efforts address key validity concerns, this system of analysis is subject to the following assumptions that guided the scoring processes and decisions:

Assumptions

A. People are being truthful when they speak (i.e., they are not intentionally trying to deceive their listener). This coding system should still work when people are mistaken about their perceptions and understandings, as long as those using the data know the subject matter well enough to discriminate between correct (appropriate) and incorrect (inappropriate) answers. Also, the "0.1 D, perceive metacognitive knowledge" code is useful for separating perceptions about one's knowledge from actual understanding performances (external validity item 3).

B. Because we don't know the individual circumstances for each student, we assume students have a common background that is described by curriculum covered earlier in the year or common experiences they would have experienced by their particular age. We do not account for the variability in prior knowledge that might occur due to learning at home or attending a different school in earlier grades.

C. Statements made in natural or classroom forms of discourse are shaped by environmental and social cues (e.g., one shouldn't dominate the conversation for too long; if a teacher asks a question, one should answer in the form requested, etc.), and therefore do not necessarily reveal a student's highest level of achievement.

D. Researchers coding the data are fully familiar with the definitions, rules and examples for this discourse taxonomy.

DISCUSSION

This study characterizes how the cognitive processes reflected in teacher prompts affect the mode of student participation in the immediate context of classroom discourse. Because the current study was conducted as a follow up study to previous research that demonstrated the effectiveness of the same teachers covering the same curriculum in the previous year, the findings illustrate how teachers might apply the described communication strategies to effectively incorporate goals for understanding causal structures into their own science curricula.

In addition to providing insight into pedagogical issues of science instruction, this study provides a new way to classify cognitive processes that are reflected in classroom discourse. While many taxonomies exist for the purposes of designing instructional objectives, activity plans and summative assessment (e.g., Anderson & Krathwohl, 2001; Bloom 1956, Gagné & Briggs 1979; Hannah & Michaelis, 1977) such taxonomies are not designed to deal with the fine grained distinctions that are necessary for discourse analysis. Due to their ability to classify behaviors at a more broad level that is suited to creating student objectives for lesson plans and end-of-unit tests, these taxonomies are more appropriate for studying the *products* rather than the *processes* of learning. As such, they are appropriate for planning summative assessment of learning, but do not offer much insight for the purposes of conducting formative assessment in context. By developing interpretation guidelines for classifying the cognitive processes exhibited in dialogue we have found a way to use the basic theoretical underpinnings of these taxonomies to study the processes of learning in classroom discourse.

The creation of a method to track cognitive processes exhibited in discourse opens new ways to study other sociocultural aspects of learning. For example, one can use the methods developed in this study to determine whether and/or how univocal and dialogic modes of discourse (see, e.g., Wertsch & Toma, 1995; Ritchie & Tobin, 2001) affect the cognitive levels reflected in student contributions. Similarly, one can also study whether and/or how teaching strategies that have been identified as best practices such as responding to student contributions with open or extending responses (see, e.g., Costa, 1991) affect the levels of cognition exhibited in student responses. Furthermore, the methodology used here can be paired with a number of measures established to study other sociocultural topics in order to examine the terms of their effects on cognitive behaviors (e.g., the function of "wait-time" in classroom dialogue, Rowe, 1974/2003).

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Appendix A: Supplement to the cognitive process definitions in Table 1

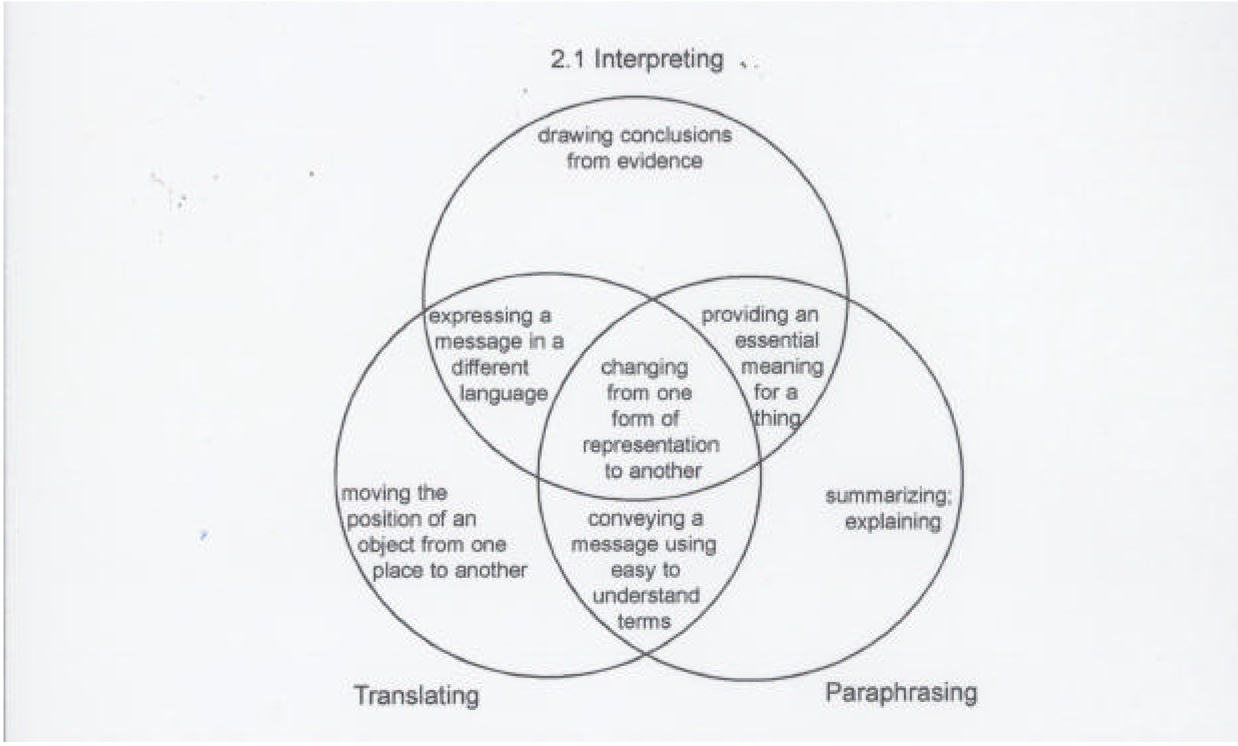

Figure 1: Ways in which various meanings of subcategory descriptors overlap to converge on the definition of the subcategory.

*Note: Only two of the four alternate names for the 2.1 *interpreting* cognitive process are depicted in the diagram to simplify the representation.

Figure 1 shows that the subcategory name and alternate names often have several meanings, some of which overlap, and some of which do not. The ways in which the meanings overlap is the key to understanding the definition of a subcategory. The central area in which all of the meanings of the subcategory descriptors converge is the definition of the subcategory (definitions appear in the column on the far right of the Cognitive Process Dimension Table). Other areas in which one descriptor overlaps with another are less central to the category definition, but often illustrate ways in which the subcategory may be used. For example, *expressing a message in a different language* and *conveying a message using easy to understand terms* offer useful illustrations of how the 2.1 *interpreting* subcategory might be used to classify particular types of statements. However, meanings that overlap between only two of the category descriptors should be viewed with caution. For example, *providing an essential meaning for a thing* is rather vague, and could apply to several different cognitive processes, most notably the 2.4 *summarizing* subcategory. Therefore, using secondary definitions should be considered as merely an aid to coding statements. One still needs to make sure that the core definition of that particular subcategory better describes the statement than the core definitions of other subcategories.

Also note in Figure 1 that the meanings in the outer edges of each circle do not overlap with the others, and therefore should never be associated with use of the subcategory to code a statement. The peripheral definition of *translating* does not apply to any cognitive process. More importantly, the peripheral definitions of *interpreting* and *paraphrasing* are misleading because they describe the central definitions of other subcategories of the cognitive process *understand* (2.5 *inferring*, and 2.4 *summarizing*, respectively).

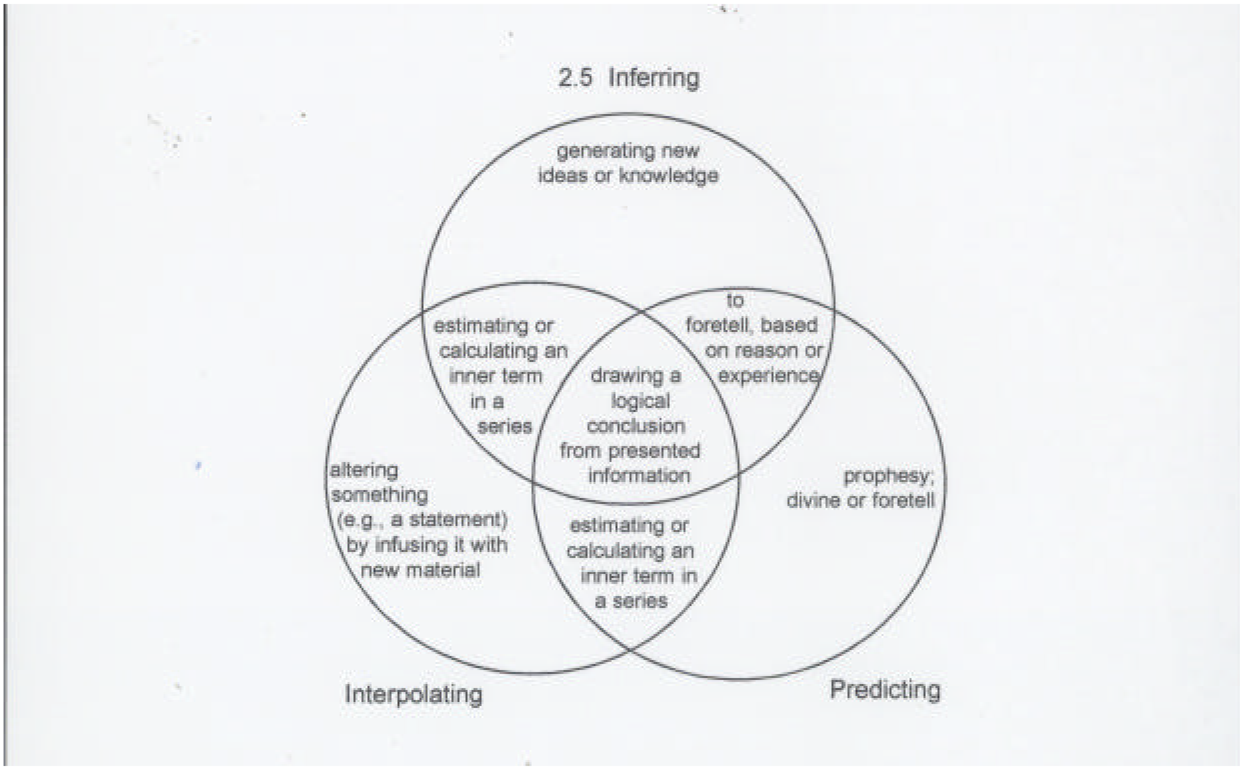

Figure 2: Ways in which peripheral meanings of subcategory descriptors violate its internal consistency and can interfere with appropriate use of the taxonomy for classifying statements.

*Note: Only two of the four alternate names for the 2.5 *inferring* cognitive process are depicted in the diagram to simplify the representation.

Figure 2 illustrates how it is also possible for the peripheral meanings of category descriptors to overlap with other categories entirely. In such cases, using the peripheral meaning of a subcategory descriptor could lead one to grossly misapply the coding scheme in classifying a statement. For example, the peripheral meaning of the 2.5 subcategory descriptor *inferring* that means *generating new ideas or knowledge* could lead one to misclassify a statement that belongs in the 6.1 *generating* subcategory of the *create* cognitive process (see the Cognitive Process Dimension Table) as the more basic cognitive process 2.5 *inferring* in the *understand* category. Instead, note that another meaning of *inferring* (i.e., *drawing a logical conclusion from presented information*) overlaps with the 2.5 *understand* category definition, and therefore should be used when using the term *inferring* to describe a statement and locate it within the taxonomy. Using the core definitions of the subcategories is the only way one can be assured that one is coding the data consistently and meeting the criteria for internal validity mentioned above.

Appendix B: Example statements and their codes

Example statement:	Taxonomy Placement:	Reason:
"The egg was sucked into the jar." [comment made during the class in which the demonstration occurred]	0.1 Ab perceive factual knowledge	The observation is *descriptive* with virtually no interpretation of the reason the egg entered the jar. Absent a causal reason for the egg entering the jar, the verb "was sucked" is more a descriptive comment of how it entered the jar than an interpretation or explanation.
"The flame made the egg get sucked into the jar."	2.7 B understand conceptual knowledge	The observation *provides an explanation* as to why the event occurred (an *explanation* contains both a cause and an effect). Note that the person is conveying his or her understanding, whether it fits with accepted scientific explanations is a different matter.
"{after the flame went out, the temperature inside the jar decreased, which caused the pressure inside to go down,} so the outside air had a higher pressure and the egg was sucked into the jar."	2.7 B understand conceptual knowledge followed by 4.2 Bc analyze structural knowledge	The "so" acts as a good indicator that the student is *organizing* the first part of the sentence (in which she explains conceptual knowledge) *in terms of an underlying cause*. This underlying cause is also a complex form of conceptual knowledge
"I like his model."	0.2 Ab perceive factual knowledge	Expressing an opinion (it is a fact that the opinion exists) without criteria on which it is based. Also, the perception refers to a symbolic representation, so it is coded as 0.1 instead of 0.2.
"I like the model we saw yesterday" [the model was not shown during the current discussion]	1.2 Ab remember factual knowledge	Expressing an opinion (w/ no criteria) from long-term memory
"I like it [the model] because it has neat handwriting." –or— "I like the model because of its arrows"	5.2 Ab evaluate factual knowledge	Expressing an opinion with its criteria as a simple perception (opinion or fact) or incomplete reasoning is a *judgment* that is expressed in terms of knowledge that is presented as an isolated fact

"I like the model because of its arrows…[teacher asks for clarification]…because there are lots of them outside to show more pressure."	5.2 Ab followed by 2.1 B understand conceptual knowledge if the student hadn't been prompted by another speaker in the middle, the entire statement could be merged into a single code, 5.2 B	The "lots of them outside to show more pressure" part shows *interpretation,* because the speaker expresses the pictorial form in the model as words. The same phrase can also be interpreted as *inferring* because she is *drawing a logical conclusion from presented information*. It would be over interpreting the participant's intent to categorize the second half of the statement as 4B, analyzing conceptual information, because it would be a stretch to note, for example, the absence of a comment about the marker color the artist chose to draw with and conclude that the speaker has *distinguished relevant from irrelevant parts …of presented material,* which is category 4.1, differentiating.
"The candle went out." (describing what happened in a demonstration, either live or videotaped)	0.1 Ab perceive factual knowledge	The student shows awareness of a phenomenon based on direct observation during the same class (therefore not coded as 1.2 remember), and the candle being extinguished is a factual event.
"The candle went out." (describing what happened in a series of diagrams or in a written passage that he or she did not create)	0.2 Ab perceive factual knowledge (from symbols)	The student shows awareness of a phenomenon through use of a symbol system with which he or she is familiar
"D equals M divided by V" or "Density equals Mass divided by Volume" (reading an equation written on the board by another)	0.2 Bc perceive conceptual knowledge	The student shows awareness of symbols in an equation, and relates conceptual knowledge (note that the student isn't necessarily demonstrating that he or she understands what the equation means (conceptual knowledge) or how to use it (procedural knowledge))
"D equals M divided by V" or "Density equals Mass divided by Volume" (reading an equation he or she had written from memory)	1.2 Bc remember conceptual knowledge	The student uses his or her long term memory to access the equation (which represents a generalization about facts; conceptual knowledge)
"That means that a change in density should bring a change in volume if the mass stays the same."	2.4 B understand conceptual knowledge	The student summarizes (abstracts a general theme from) the meaning of a set of symbols that represent an idea (conceptual knowledge)

"I would put 10 grams here and 1 cubic centimeter here and divide them (to find the density)"	3 Ca apply procedural knowledge	The student demonstrates knowledge of how to use an equation (apply) to find an answer. The steps he or she lists represent the procedures inherent to the task. If the student had never before plugged numerical values into this equation, the cognitive process would be coded as 3.2, but if the student was familiar with using the equation in this manner, it would be coded as 3.1.
"I think I would put 10 grams here and 1 cubic centimeter here and divide them (to find the density)" Or "I know that I would put 10 grams here…"	0.1 Db perceive metacognitive knowledge followed by 3.1 C.a. apply procedural knowledge	The speaker could preface the above statement about applying procedural knowledge with "I think" or "I know," but the whole statement would not be nested within the perceive metacognitive knowledge classification because the speaker makes explicit his or her thinking of the procedural knowledge, such that the teacher would be able to determine whether the student has a good grasp of the procedure.
"That equation is hard for me to understand."	0.1 Db perceive metacognitive knowledge	The student shows awareness of his or her ways of making sense of something (this statement reveals a student's perception about his or her understanding, but does not directly give evidence of how the student understands (or misunderstands) the equation, so it cannot be coded using the 2 *understand* category)
"I don't know what happened." (in response to a request to describe what happened in a demonstration)	0.1 Db perceive metacognitive knowledge	In this statement, the speaker shows a perception about his or her own level of knowledge. The statement is too ambiguous to code more precisely—the student could be referring to not having seen the sequence of events in the demonstration (which would be coded as 0.1 Ab, perceive factual knowledge), or the student might be expressing that he doesn't think he can explain why the parts of the demonstration behaved as they did (0.1D [2.7 B] perceive metacognitive knowledge about understanding conceptual knowledge).

"I don't know why." (referring to why something happens) or "I think I know why."	0.1 Db [B] perceive metacognitive knowledge about conceptual knowledge	The student shows awareness of his or her mental state concerning conceptual knowledge, but does not reveal the conceptual knowledge in a way that would allow the teacher to corroborate the statement (e.g., either by positing a correct or incorrect explanation of the phenomenon). While the "I think I know" might seem to simply signify a level of certainty, it also acts as an indication of a type of knowledge one does or does not know (the "why" is a form of conceptual knowledge).
"I'm not sure what I know."	0.1 Db perceive metacognitive knowledge	The student is reflecting on a mental state
"I liked watching the demonstration better than doing homework."	2.6 D.b. compare metacognitive knowledge	The student not only shows awareness of a mental state, but directly compares two activities in terms of his/her preferences (notice that criteria are not given for why s/he likes something, so the statement is not evaluative). The student is comparing the activities in terms of his or her preferences (mental state), rather than in terms the usefulness or appropriateness of general cognitive strategies, so it is coded as Db instead of Da.
"I didn't understand this yesterday when I was doing my homework."	1.2 D.b. remember metacognitive knowledge	The speaker *remembers* a mental state he or she had before coming to class that day.
"I don't remember how I came to that conclusion." (referring to a subject-specific task done in class that day)	0.1 D.b. [C] perceive metacognitive knowledge about procedural knowledge	Even though the student uses the word *remember*, he or she refers to recalling an event that occurred in the current class period, which would be coded as perceive rather than as accessing long-term memory.
(A student reads aloud an explanation from a source that he or she did not create)	0.2 B perceive conceptual knowledge	Simply reading aloud doesn't necessarily imply that the student understands what he or she is reading. We can say that the student is perceiving symbols, and the information relayed is that of conceptual knowledge.

(A student reads aloud an *explanation* that he or she had written in response to, and shortly after, seeing a demonstration)	2.7 B understand conceptual knowledge	The student's response shows his or her own understanding of the conceptual knowledge (the distinction that the understanding is based on perception (0.1) can be preserved in a second set of coding if it is of interest to the researcher)
(A student reads aloud an *explanation* that he or she had written in response to a demonstration she had seen a week before recording the incident)	2.7 B understand conceptual knowledge	Even though the original task had involved long term recall, we would be missing the higher process that the student shows in constructing an explanation if we were to code this as remember (the distinction that the understanding is based on memory (1.1) rather than perception (0.1) can be preserved in a second set of coding if it is of interest to the researcher)
"The candle will go out. [teacher asks why] Because there won't be enough air."	2.5 Ab perceive factual knowledge [teacher statement coded as 2B] followed by 2.5 B understand conceptual knowledge	The student shows his or her reasoning (the logic by which he or she makes an inference) in the follow up statement. Note that this sequence needs to be coded in three parts—the student answer, the teacher prompt and the student response. The student gives a prediction only about a specific fact that can be isolated from further context, the teacher prompts for an explanation, and the student responds with his/her reasoning.
"The candle will go out because there won't be enough air."	2.7 B explain conceptual knowledge	The student gives both the effect (the candle going out) and the cause (not enough air), which constitutes an explanation (cognitive process 2.7) of the concept (B) of how the dynamics of the situation work.
"I remember the formula." Or "I remember it." Or "I know it."	0.2 Db[1.2 A] perceive metacognitive knowledge about remembering factual knowledge (simply coded as as 0Db for the statement "I know it.")	The student only reveals the perception of his or her mental state (that he or she remembers an item, concept or procedure), but does not reveal the content. Without revealing *what* he or she remembers, the student isn't allowing the teacher to see if his or her memory is accurate (for example, if a student were to simply answer "I know the answer to this" instead of giving the answer on a test, he or she would not actually be demonstrating his or her knowledge for the teacher to evaluate.)

"I remember the formula for density is D equals M over A." or "I know the formula for density is D equals M over A"	1.2 A.a remember factual knowledge	Student retrieves specific content matter from long-term memory
"I don't remember the chemical composition of water."	0.2 D.b [A] perceive metacognitive knowledge about factual knowledge	The student specifies only his/her mental state about a topic, but doesn't give a particular memory; this type of statement reflects the student's perception that he or she doesn't remember, when in fact he or she may.
"The chemical composition for water is H-three-O"	1.2 A remember factual knowledge	Student reveals specific information from long term memory (inaccuracy doesn't affect the coding)
"I don't understand how to use that equation."	0.2 D.c. [3.1 C] perceive metacognitive knowledge [about applying procedural knowledge]	This statement reveals the student *perception* about a cognitive ability (that he or she doesn't know how to apply the formula), but until the student actually tries to apply the formula, we don't know if it is the case or not. The student will have to either specify which steps he or she has trouble with or try to apply the formula for the teacher to better understand the student's thinking in the *apply* cognitive process.
"I don't understand what you mean." OR "I understand."	0.2 Db perceive metacognitive knowledge	These statements are so broadly stated that one would need further information to be able to address the student's needs. The speaker's perception is referencing his or her understanding level based on symbolic representation—oral language.
"I don't think you understand what I'm saying." (after trying to explain conceptual knowledge in an earlier statement)	0.2 D [2 B] perceive metacognitive knowledge about understanding conceptual knowledge	The speaker makes a perception (0.2) about another person's mental state (Db), the content of this perception is about understanding (2) the conceptual knowledge (B) of "what I'm saying"

"You should remember this from last week."	0.2 Dc [1] perceive metacognitive knowledge about remembering	This statement shows a perception (opinion; expected level of awareness) about a person's cognitive ability (remembering a certain type of knowledge—in this case, what "this" refers to is left unspecified, so we don't assign a knowledge type within the nested code that reveals the content of the statement).
"Heat is when the molecules move around." Or "The molecules are moving because of the heat."	1.2 A	This is a superficial reference to molecules' behavior that doesn't show a logical connection between heat and molecules moving. The way it is expressed, it may just be a memorized fact; the definition of what heat is without further elaboration of why the molecules move.
"When the object gets hotter, the molecules move around faster."	2.7 B	This statement has both a cause and effect (2.7), and shows that the student is able to connect the concepts of heat (amount of heat) and the relative motions of molecules.
"The molecules move around more because they have more energy."	2.7 B	This statement has both a cause and effect (2.7), and explicitly notes the interrelationship among the cause and effect.
(after hearing that the teacher will hold a metal rod in a Bunsen burner flame) "I think the metal will glow red after a while."	2.5 A	This statement gives a prediction (2.5), but does not give any reason for the prediction; the greater context is not referenced in a way that would give us confidence that the speaker recognizes interrelationships among the mechanisms that would make the metal glow in the first place. It is therefore coded as A factual knowledge instead of B conceptual knowledge. This particular example could also be a prediction based on personal experience, but it still doesn't illustrate conceptual knowledge that connects heat to light.

(after hearing that the teacher will hold a metal rod in a Bunsen burner flame) "I think the heat will make the metal glow red after a while."	2.5 A or 2.7 A	This statement gives a prediction (2.5—metal will glow red), and a superficial reason for that outcome to occur. Any additional reference that shows the relationship between the heat and glowing red would constitute B conceptual knowledge.
(after hearing that the teacher will hold a metal rod in a Bunsen burner flame) "I think the heat will make the molecules move so fast that they'll give off light."	2.5 B or 2.7 B	This statement is also in the form of a prediction (2.5), but it also shows a conceptual link between the heat and the reason it will glow.
(after hearing that the teacher will hold a metal rod in a Bunsen burner flame, and the preceding student comment was: "Well, when molecules get really hot, they move so fast that they give off light energy.") "Yeah-I think the heat will make the metal glow red after a while."	2.5 B or 2.7 B	This student builds on another's reference to molecules moving fast being connected to light energy so there are enough links among the concepts (through the student's agreement with the previous statement) to imply a conceptual knowledge of the relationships among the different components that connect the concept of *heat* to the predicted outcome of the metal rod glowing red.
"I think the metal will glow red and will begin to bend because the molecules will be moving so fast that it will change to a liquid."	4.1 B or 4.2 B	This chain of cause and effect statements are linked in ways that show the relevance of one cause to the next effect, and then to the subsequent effect. Several elements of related phenomena are cited along with their interconnections.
(in response to a teacher asking what will happen when she slides a block coated with sandpaper along the floor, or in response to seeing the demonstration enacted) "The friction will make it stop." Or "I think the friction makes it stop sliding."	2.5 A or 2.7 A	This shows a prediction or inference, but does not show an interrelationship among the elements. This statement can't answer the question "What about the friction will make its motion stop?" so it is not revealing conceptual knowledge. In other words, the statement is too ambiguously worded to show us that the student knows the specific ways in which friction is connected to, or can interfere with, an object's motion. We could think of this as a token use of the word "friction."

(following a statement that the object's and/or floor's surfaces are rough): "Yeah—I think the friction will make it stop."	2.5 B or 2.7 B	This student builds on another's reference to surface textures and therefore implies a conceptual knowledge of the relationship between the two concepts.
"I think it'll stop because the little particles that stick out of its surface will act like little brakes on the floor."	2.5 B or 2.7 B	This prediction more explicitly shows the interrelationship between surface texture and the oppositional nature of the force of friction.
"Gravity makes the apple fall." Or "The force of gravity makes the object fall to the ground."	1.2 A	This statement reveals only the level of *remembering factual knowledge* because the student does not show the interrelationship between gravity and an object's movement toward the ground.
"Gravity will make the apple fall when you let go of it."	2.5 A	This statement predicts an outcome but reveals only the level of *factual knowledge* because the student does not show the interrelationship between gravity and an object's movement toward the ground.
"Gravity makes the apple fall because it pulls the object and the Earth toward each other."	2.5 B or 2.7 B	This statement shows an inference that is supported by conceptual knowledge; the link between gravity and how it acts on both the object *and* the Earth.
"Gravity pulls the object and the Earth toward each other, and the Earth has so much more mass compared to the apple that the apple will move further than the Earth moves."	4.1 B or 4.2 B	This statement shows both an explanation of conceptual knowledge ("Gravity pulls the object and the Earth toward each other") and links it to the related concept of mass (mass differentials serve as the second cause in this statement) to explain the effect that the apple moves further than the Earth does.