A FRAMEWORK FOR ANALYZING REASONING IN SCIENCE CLASSROOM DISCOURSE

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Abstract

Although students' ability to participate in scientific argumentation is considered a major objective of early science education, analyses of classroom discourse have revealed that unsupported conjectures are prevalent especially in elementary school (Newton & Newton, 2000). Even in secondary school, establishing a classroom culture of scientific reasoning seems difficult to achieve (e.g., Osborne, Erduran, & Simon, 2004). Many frameworks have been developed to help identify high-quality student reasoning when it occurs in classrooms; the present paper combines and extends on this prior work to develop a new analytic tool for reasoning in science classroom discourse. The instrument, *Reasoning in Science Classroom Discourse*, is intended to provide a means for measuring the quality of student reasoning in whole-class discussions, captures teachers' and students' co-constructed reasoning about scientific phenomena. This paper describes the features of the instrument, illustrates how it can be applied to an instance of classroom reasoning, discusses its strengths and weaknesses, and makes recommendations for future analyses.

Introduction

Students' ability to reason from evidence and participate in scientific argumentation is considered a major objective of science education reform (American Association for the Advancement of Science, 1993; National Research Council, 1996). According to Duschl and Gitomer (1997), this involves "the development of thinking, reasoning, and problem-solving skills to prepare students to participate in the generation and evaluation of scientific knowledge claims, explanations, models, and experimental designs" (p. 38). Similarly, Driver et al. (1994) stated,

> Learning science involves young people entering into a different way of thinking about and explaining the natural world; becoming socialized to a greater or lesser extent into the practices of the scientific community with its particular purposes, ways of seeing, and ways of supporting knowledge claims (p. 8).

This learning process is dependent upon the intervention of the teacher, who should seek to provide both the "appropriate experiential evidences and to make the cultural tools and conventions of the science community available to students" (Driver et al., 1994, p. 7).

Unfortunately, analyses of classroom discourse have revealed that unsupported student conjectures are prevalent, especially in elementary school (Newton & Newton, 2000). Even in secondary school, establishing a classroom culture of scientific reasoning seems difficult to achieve (e.g., Osborne, Erduran, & Simon, 2004). Several prior studies have explored how the process of student reasoning might be supported in science classrooms, and have contributed a number of analytic approaches to help identify high-quality reasoning when it occurs. Some of these approaches build upon Toulmin's (1958/2003) *The Uses of Argument*, and others make distinctions based on the quality of reasoning (Carey, Evans, Honda, Jay, & Unger, 1989; Driver et al., 1994; Kawasaki, Herrenkohl, & Yeary, 2004; Tytler & Peterson, 2005); however, none integrate methods for analyzing the contribution of the teacher to supporting high-quality reasoning.

Based on these prior studies, we developed an instrument that combines Toulmin's elements of reasoning, different qualities of evidence-based reasoning, and the degree of teacher support. This instrument, intended to provide a means for measuring the quality of scientific reasoning in whole-class discussions, is called *Reasoning in Science Classroom Discourse*. This instrument, an adaptation of the *Model for Scientific Reasoning* (Brown et al., 2008) to whole-class discussions, provides a framework for examining teachers' and students' co-constructed reasoning about scientific phenomena.

Theoretical Background

Our framework for analysis of science classroom discourse draws upon and combines multiple areas of the literature; this section will briefly establish the role of evidence in the scientific enterprise, and will then address evidence as a central tenet of reform-based science education. Finally, we review features of prior instruments created to analyze reasoning in classroom discourse.

The Role of Evidence in Science and Science Education

The scientific endeavor is by nature based upon the collection and analysis of evidence, and arguments based on evidence form the foundation of scientific thinking (Kuhn, 1993). Hempel (1966) wrote, "no statement…can be significantly proposed as a scientific hypothesis or theory unless it is amenable to objective empirical test" (p.30). By this standard, all scientific ideas must be subjected to the rigor of reality, and then evaluated by evidence in the form of observations made about the natural world.

It follows, then, that reform efforts intended to make students' experience in school more closely resemble the actions and thinking processes of practicing scientists should involve evidence at its core. An overview of the literature base in science education shows that argumentation and evidence-based reasoning have been among the goals and methods of teaching reforms for the past 40 years. Bruner (1961) stated that learning through science inquiry is "in its essence a matter of rearranging or transforming evidence" (p. 22), and thus evidence should play a central role in developing students' understanding of where scientific ideas come from.

An unequal focus on the facts of science in traditional classrooms over the processes that produced them led to what Schwab (1962b) termed an "unmitigated *rhetoric of conclusions* in which the current and temporary constructions of scientific knowledge are conveyed as empirical, literal, and irrevocable truths." The rhetoric of conclusions "is a structure of discourse which persuades men to accept the tentative as certain, the doubtful as the undoubted, by making no mention of reasons or evidence for what it asserts, as if to say, '*This*, everyone of importance knows to be true'" (Schwab, 1962b, pp., p. 24). Schwab (1962a) posited that students should learn about the means by which truth is derived within a discipline, or the syntactical structure of a discipline. Such learning would include the collection, analysis, and interpretation of empirical evidence, and then the development of knowledge claims supported by this evidence.

The American Association for the Advancement of Science ([AAAS], 1990) has stated that learning science should be consistent with the nature of scientific inquiry, meaning that it should begin with questions about nature, concentrate on the collection and use of evidence, including the formulation of arguments from evidence, and be situated within the context of history. This goal was further reinforced by the National Research Council's [NRC's] *National*

Science Education Standards (1996), which emphasized the importance of evidence in the science classroom when they set out the five essential features of inquiry. A unifying characteristic of the 'Essential Features' is their focus upon the role of evidence in scientific investigations. These five features are shown in Table 1.

Table 1. *Essential Features of Science as Inquiry.*

Essential Feature	
1	Learners are engaged by scientifically oriented questions.
2	Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
3	Learners formulate explanations from evidence to address scientifically oriented questions.
4	Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
5	Learners communicate and justify their proposed explanations.

These 'essential features' are also reflected in the NRC's *Fundamental Understandings in Science Inquiry*, which focus upon what students should know about the nature of science itself; among these targeted 'understandings' for middle school students is the statement that "Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories" (p. 20).

Duschl (2003) has interpreted the NRC's Essential Features as containing three transformations in scientific inquiry: data to evidence, or determining if data are anomalous or count as valid evidence; evidence to patterns, or searching for patterns in and generating models for data; and patterns to explanations, or developing explanations on the basis of the evidence selected. Assessment of inquiry, then, should focus upon students' ability to make these transformations.

The ability to reason from evidence, along with understanding the central role evidence place in science, is a core element in the development of scientifically literate students. Bybee (2002) argued that the capability to take part in a scientific argument is related to the area of conceptual as well as procedural scientific literacy. In its assessment framework, the Organization for Economic Co-operation and Development [OECD] (2003) described the role of evidence in scientific literacy as follows:

> Scientific literacy…gives higher priority to using scientific knowledge to "draw evidence-based conclusions"…the ability to relate evidence or data to claims and conclusions is seen as central to what all citizens need in order to make judgments about the aspects of their lives that are influenced by science. (p. 137)

Based on the priorities placed upon evidence-based argumentation in both domestic and international contexts, it seems prudent that the manner in which students argue in classrooms, and the role evidence plays in those arguments, should be a part of the agenda for educational researchers.

Studies on the Role of Evidence in Science Classrooms

Of note in the aforementioned policy and assessment documents is that evidence should not merely be collected in science classrooms; it also should be used as a basis to support scientific arguments (Driver, Newton, & Osborne, 2000). To determine when and how evidence-based arguments are taking place, several studies have turned to Toulmin's (1958/2003) foundational framework for the analysis of arguments (e.g. Driver et al., 2000; Jimenez-Alexandre, Rodriguez, & Duschl, 2000; McNeill, Lizotte, Krajcik, & Marx, 2006; Simon, Erduran, & Osborne, 2006). Toulmin describes how an argument consists of a piece of data and a claim, linked together to make a warrant. Evidence then supports this argument in the form of backing (Toulmin, 1958/2003). The relationship among these elements of an argument is represented in Figure 1.

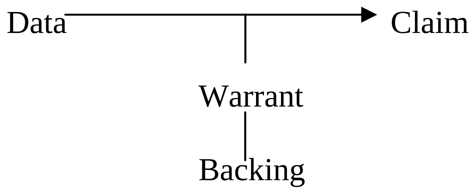

Figure 1. Toulmin's (1958/2003) framework for arguments

Analyses Based on the Elements of Arguments

Many studies have applied Toulmin's framework, with a variety of adaptations, as an analytic tool for determining the quality of students' reasoning in writing (e.g. Kelly & Bazerman, 2003; McNeill et al., 2006; Sandoval, 2003; Sandoval & Millwood, 2005). Discourse in science classrooms, however, is a different kind of communication, involving multiple speakers and particular ways of knowing (Edwards & Mercer, 1987; Lemke, 1990). Therefore, analyses of classroom discourse have necessitated different kinds of analytic frameworks. Eliciting and supporting student contributions involves intervention and support from the teacher; multiple student speakers may develop the same idea; and systematic reasoning structures become more challenging to track. For these reasons, the number of studies that have attempted to adapt Toulmin's framework to classroom discourse is much smaller.

In an analysis falling in the process-product tradition (Brophy & Good, 1986), Russell (1983) explored how teacher questions helped students develop arguments on the basis of scientific evidence. Taking whole arguments as a unit of analysis, Russell developed a framework that combined research on attitudes toward authority with Toulmin's argument structure. Russell concluded that the manner in which teachers use questions could serve to reinforce traditional authority structures and were geared toward getting students to provide the answers teachers were looking for in the arguments.

Felton & Kuhn (2001) developed a coding system to analyze argumentative dialogues, albeit in the domain of capital punishment instead of science. Their framework identified two forms of development in argumentative discourse; first, skill in meeting an activity’s objectives by directing the course of an argument; and second, skill in refining the goals being pursued in the argumentation. Codes for transactive questions, transactive statements, and nontransactive statements were applied to individual speaking turns; through this system, the authors were able to identify counter-arguments, rebuttals, and patterns in these and the other codes during dialogues. The authors concluded that adults argued more strategically than teens, whereas teens made use of similar strategies in disagreement and agreement situations.

Exploring the Quality of Student Reasoning

Another set of studies took a higher-level approach with coding systems or analytic frameworks that explored the *quality* of backing students used in scientific reasoning. In coding clinical interviews completed by students after participating in a unit focusing on the formulation and testing of theories, Carey et al. (1989) define three levels of understanding of the nature of science. The first level involves no clear distinction between theory and evidence; that is, collecting facts and seeing if something might work. The second level requires some distinction between theory and evidence; namely, that science is seen as a search for evidence. The third level makes a clear distinction between theory and evidence, where the cyclic, cumulative nature of science is acknowledged, with its goal to construct explanations of the natural world.

Other studies have used similar distinctions to obtain a measurement of the quality of scientific reasoning based on students` ability to differentiate between theory and evidence used as backing. Tytler & Peterson (2005) and Driver et al. (1996) discern between three different levels of epistemological reasoning for student explanations of science phenomena. The first level involves reasoning from phenomena, where explanations of events are equivalent to observing the event itself. The second level, relation-based reasoning, involves generalizations based on causal or correlational relationships. The third level, model-based reasoning, involves the evaluation of theories or models on the basis of evidence. Kawasaki, Herrenkohl, & Yeary (2004) applied this framework to whole-class discussions and small-group interactions, and determined that by making norms of scientific argumentation explicit with these students, students participated more in classroom discussions and became more involved in the process of developing shared meaning and applying that meaning to various situations.

In an analysis of a whole-class discussion, Jimenez-Alexandre et al. (2000) distinguished between ‘doing the lesson,’ or engaging the ritual activities and procedures of school science, and ‘doing science,’ a more principled ways of engaging in scientific dialogue and argumentation. Instances of ‘talking science’ were further coded according to Toulmin’s elements of argument (argumentative operations) as well as epistemic operations, including induction, deduction, and causality. Jimenez-Alexandre et al. found that a large part of interactions in the discussion could be classified as ‘doing the lesson,’ but that in instances of ‘doing science,’ students developed a variety of arguments.

Prior Studies on Evidence in Science Classroom Discourse

Previous studies indicate that argumentation seldom occurs in lessons, and that discussions are more often than not dominated by unsubstantiated assertions (Jimenez-Alexandre et al., 2000). In fact, the absence of opportunities for students to participate in arguments within science lessons, due in part to teachers’ lack of pedagogical skills to support this argumentation, places significant roadblocks in the way of realizing this scientific norm in classrooms (Driver et al., 2000).

However, many studies have shown that children are capable of participating in argumentative discourse and supporting their claims with evidence. For example, elementary school children already possess the foundational understandings of hypothesis testing and evidence evaluation (Wilkening & Sodian, 2005). In a longitudinal investigation of the development of scientific thinking in elementary school children, Tytler & Peterson (2005) observed an abrupt rise in the quality of scientific thinking between the ages of 5 and 10. Studies of the quality of argumentation in secondary school students have also indicated possible influences on conceptual understanding (Tytler & Peterson, 2005)

Kawasaki, Herrenkohl & Yeary (2004) raised the development of elementary school students' epistemologies of science, drawing upon Driver et al.'s (1994) framework of Phenomenon-Based, Relation-Based, and Model-Based reasoning. Kawasaki et al. found that, when provided with procedural and intellectual roles through a series of investigations of sinking and floating, the quantity and quality of students' participation in class discussions increased. More specifically, students moved away from phenomenon-based reasoning – that is, conflating the existence of a phenomenon with its explanation – toward relation-based reasoning, which relies upon the evaluation of theories and models based upon evidence.

The Role of Teachers in Supporting Scientific Argumentation

Another feature of reasoning in science classrooms is the extent to which the teacher supports or actually participates in the process of student argumentation. While the aforementioned studies have explored the quality of reasoning in small group and whole-classroom talk, they have not explicitly explored the extent to which the teacher takes steps to activate and advance student argumentation and evidence-supported reasoning.

The support teachers provide during whole-class discussions can also be conceived of as *scaffolding* student reasoning. Bruner (1960) defined scaffolding as “a way that assures that only those parts of the task within the child’s reach are left unresolved, and knowing what elements of a solution the child will recognize though he cannot yet perform them” (p. xiv). Through the strategies teachers use during discussions, teachers can coordinate a zone of social learning around students (e.g., Lave & Wenger, 1991; Vygotsky, 1978), which has the students and what they are able to collectively establish through discussion at its center, and the assistance the teacher provides on the outside. Therefore, identifying the manner in which teachers are contributing to the reasoning being done by students can provide a measure of the amount of scaffolding being provided. If students are engaging in high-quality reasoning only when involved in IRE-type exchanges with the teacher (Mehan, 1979), then it is clear that the students’ ability to reason from evidence. In contrast, if teachers are asking open-ended questions that are true requests for information from students (Cazden, 2001), and students are able to continue reasoning on their own without intervention from the teacher, then one may conclude that students’ ability to reason has developed beyond the point at which it is heavily reliant upon the teacher’s intervention.

Prior research on teaching has referred to Wagenschein and the traditional orientation toward a ‘Socratic Seminar.’ Possible questions are, for example, ‘*What are we speaking about now?’, ‘What do we want to bring out?’, ‘How far have we come?’, Who has understood what she/he has said?’* Adjacent to these approaches should also be questions that are based upon advancing students toward conceptual goals (Einsiedler, 1994).

Duschl and Gitomer (1997) described assessment conversations as instructional dialogues specially designed to engage students in discussion of diverse student-generated ideas focused upon evidence and scientific ways of knowing. In the ‘Science Education through Portfolio

Instruction and Assessment' (SEPIA) project, these assessment conversations are used to help teachers provide scaffolding and support for students' construction of meaning by carefully selecting learning experiences, activities, questions, and other elements of instruction. A central element of the assessment conversation is a three-part process that involves the teacher *receiving* student ideas through writing, drawing, orally sharing, so that students can show the teacher and other students what they know. The second step involves the teacher *recognizing* students' ideas through public discussion, and the third has the teacher *using* ideas to reach a consensus in the classroom by asking student to reason on the basis of evidence. Focusing the conversation around evidence makes this example of formative assessment specific to science inquiry. Duschl & Gitomer suggested that teachers should focus less on tasks and activities and more upon the reasoning processes and underlying conceptual structures of science.

In a qualitative study of his own teaching, Yerrick (2000) followed general guidelines for his teaching to help students formulate arguments by basing instruction on students' own questions. Discussions after activities involved students discussing their findings with the whole class, and usually ended with students agreeing on an explanation or returning to their experiments to gather more data. In comparing interviews at the beginning and end of the school year, Yerrick found that students' sophistication in formulating scientific arguments in response to the questions investigated throughout the school year did improve. However, to what extent these questions or prompts actually lead to an increase in the quality of students' scientific argumentation and evidence-based reasoning has to date not been empirically tested in a comparative study.

More recent studies have found that varying levels of teacher intervention may help students to develop conceptual understanding (Furtak, 2006; Scott, 2004; Scott, Mortimer, &

Aguiar, 2006), suggesting that ongoing classroom discussions may involve different levels of support from the teacher. For example, increases in students' conceptual advancement have been suggested as a vehicle to promote reasoning about science phenomena through the repeated need for empirical support of arguments (see Tytler & Peterson, 2005).

Toward a New Framework for the Analysis of Evidence in Science Classroom Discourse

As indicated in the sections above, studies of argumentation in science classrooms have almost exclusively relied upon Toulmin's work as an analytic tool (Toulmin, 1958/2003). Yet Toulmin's model does not cleanly apply to the messiness of discourse created by multiple participants in science classrooms. As a result, many researchers have opted to focus on only some aspects of the total structure of an argument as defined by Toulmin (e.g. Erduran et al., 2004).

Given this challenge, the conceptual model we developed in our research collaboration takes as its backbone Toulmin's features of an argument (i.e., claims, data, warrants, and backing), but draws upon additional theories beyond Toulmin's to further our understanding of argumentation and to inform our conceptualization of student reasoning in science classrooms. Additionally, we draw upon Duschl (draft) and McNeill, Lizotte, Krajcik, & Marx (2006) for insight into the role of evidence and argumentation specific to the context of science education. The conceptual model for argumentation is shown in Figure 2 below; see Brown et al. (2008) for more information regarding the development of this model.

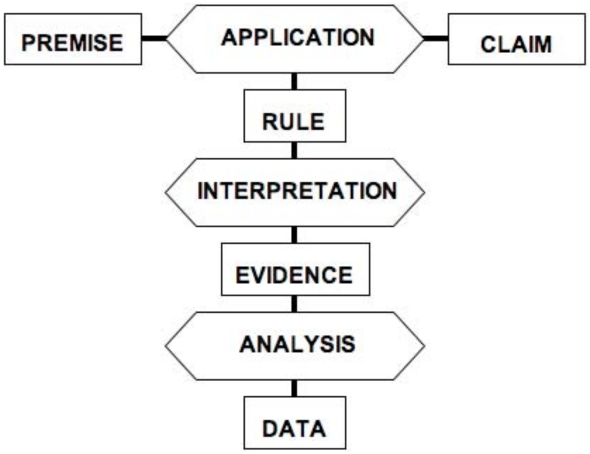

Figure 2. Model of scientific reasoning

This conceptual model for scientific reasoning distinguishes between two distinct classes of information: Component and Process. A Component, in general, refers to statements that frame and place the argument in context. The model consists of five components, based on Toulmin’s (1958/2003) model and Duschl’s (2003) framework for assessment of inquiry: Premise, Claim, Rule, Evidence, and Data. *Premise* is a statement describing the specific circumstances acting as an input that will result in the outcome described by the claim. The premise often identifies a specific object and a relevant property (e.g., “this box is heavy”). A *Claim* is a statement about a specific outcome or state: what something will do in the future (prediction, e.g., “this box will sink”), has done in the past (observation, e.g., “this box sank”), or is (conclusion, e.g., “this substance is an acid”). It is specific to a single set of circumstances, generally a particular object in a particular time and place. A *Rule* is a statement describing a general relationship between two properties (e.g., “something that is an acid tastes sour”) or a property and a consequence of that property (e.g., “something that is heavy will sink”). This relationship is general in the sense that it is expected to hold even in contexts and circumstances not previously observed. *Evidence* is composed of statements describing a contextualized relationship between two properties or a property and a consequence of that property. This relationship is contextualized in the sense that it describes (or assumes) a specific set of circumstances in which the relationship has been actually observed to be true. *Data* are statements describing a specific relationship between two properties or a property and a consequence of that property. This relationship is specific in the sense that it describes (or assumes) a specific, single event that has been either observed or made up.

The Process pieces of the conceptual model are composed of three parts - Application, Interpretation, and Analysis. *Application* refers to the process by which the rule is brought to bear in the specific circumstance(s) described by the premise. It establishes the probability or necessity of the claim, often by logical deduction in simple cases. *Interpretation* is the process by which multiple pieces of evidence are compared and integrated or synthesized. It establishes the probability or necessity of the rule, often by generalization in simple cases with only one piece of evidence. *Analysis* is the process by which multiple data are compared and integrated or synthesized. It establishes the probability or necessity of the evidence, often by extrapolation in simple cases.

This paper takes the conceptual model one step further by adapting it for use in the analysis of science classroom discourse. The extent to which particular student claims about certain premises are supported (or not) by data, evidence, or rules, is analyzed, as is the extent to which the teachers guiding the discussion supports and participates in that process of reasoning. In addition, the conceptual basis of the reasoning is coded. The following section will describe features of the instrument, describe how it is to be applied to instances of classroom discourse, and illustrate how it is applied to a short excerpt of science classroom talk.

The Research Collaboration

The analytic framework presented in this paper was developed in collaboration between German and American researchers and was funded by the National Science Foundation and the Deutsche Forschungsgemeinschaft (German Research Foundation). This collaboration was founded upon complementary videotaped datasets between the two groups. Researchers in both countries had collected elementary and middle school data on students' whole-class discussions during inquiry-based units about the concept of sinking and floating). This work allowed us to explore the use of evidence across multiple grade levels in similar content areas, as well as teacher practices in different educational systems.

Reasoning in Science Classroom Discourse: An Overview of the Instrument

The instrument captures teachers' and students' co-constructed reasoning about science phenomena and quality of the backing for those claims. On a continuum of reasoning, the most sophisticated science discourse is conceptualized to consist of claims about science phenomena that are backed up with a generalized statement about relationships between properties (a rule). In addition to this statement of a rule, (empirical) backing such as reference to observations (data) or summaries of comparisons between that data (evidence) may be used as backing. The least sophisticated reasoning is considered to consist of a single claim or claims without any backing.

Given its in-depth and interconnected nature, the *Reasoning in Science Classroom Discourse* instrument is not intended for use in real-time analysis of science classroom discourse; rather, it is intended for analyses of transcribed classroom discourse. The framework is intended for use on portions of lessons where reasoning about science phenomena in classroom discussions is *expected* to happen. Within these discussion segments, related elements of reasoning are identified within what we call *reasoning units*, which are defined as coherent segments of reasoning that refer to the same claim, premise or both. Reasoning units can be of any given length, consisting of only a piece of a student or teacher speaking turn, or including a number of speakers across several minutes of classroom talk.

Three sets of codes are applied to each reasoning unit. From the combination of elements of reasoning in each reasoning unit we can determine the *quality of reasoning* which addresses the extent to which claims are backed up with data, evidence, and rules. The *teacher's contribution* in each reasoning unit identifies the extent to which teachers prompted for elements of reasoning or provided these themselves and indicates the level of support provided by the teacher during the unit. Finally, coding the *conceptual level* within each reasoning unit allows the identification of the conceptual basis of claims being made. The relationship between the unit of analysis and coding categories is shown in Figure 3.

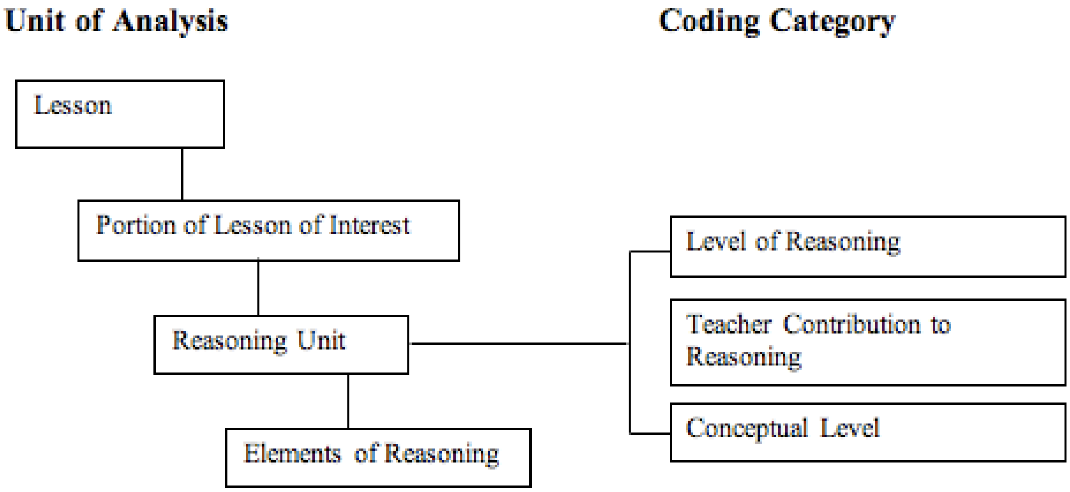

Figure 3. Overview of Videotape Coding Framework: Reasoning in Science Classroom Discourse

The following sections will focus first upon identifying the elements of reasoning, which are identified with instrument first to determine the unit of analysis. Then, we will discuss the level of reasoning, teacher contribution to reasoning, and conceptual level codes. Finally, we will demonstrate how these codes can be applied in a sample transcript from a whole-class discussion. A complete copy of the *Reasoning in Science Classroom Discourse* instrument is included in the Appendix.

Elements of Reasoning

The elements of reasoning (premise, claim, data, evidence, rule) as described above describe basic functions of statements by teachers and students within classroom discourse about science phenomena. In classroom talk, the premise is often the subject of the sentence that contains the claim, while the claim is often the verb that describes what the subject has done, is doing, or will do. For example, the statement ‘the boat will float’ contains a premise that is the subject of the sentence (‘the boat’), as well as a claim that is also the verb in the sentence (‘will float’). The backing provided for this claim-premise statement is often stated implicitly or explicitly as a ‘because’ statement; that is, the statement ‘the boat will float because of its shape’ contains a premise, claim, and backing (‘because of its shape’). All statements of backing are classified as being data, evidence, or a rule. In this case, the backing is further classified as *data*, since it relies upon a characteristic or property of an object. Specific definitions for identifying the elements of reasoning are illustrated in Table 2.

Table 2. *Elements of Reasoning in Science Classroom Discourse.*

Elements of Storyline	Elements of Reasoning (General)	Elements of Reasoning (Specific)	Definition
Premise	Premise	Premise	A statement describing the relevant characteristics or properties of the object about which the Claim is made (i.e., the conditions for the claim). The Premise is the "given" information from whence the Claim is derived upon. Includes: object, state of an object, general expression ("subject of reasoning"), point of reference
Claim	Claim	Claim	A claim about a specific premise. This includes either what something will do in the future (prediction/ presumption), or is happening in the present or past (conclusion or outcome). A claim could be expressed as a relationship among datapoints (evidence), statements about single datapoints (data), and statements of generalized relationships (rules); however, it is an ***isolated*** statement that is not used as backing.
	Backing	Data	A supporting statement (backing) describing the outcome of a single specific experiment or a single observation in a personal anecdote or prior knowledge / books / tests ***in support of a claim***.
		Evidence	A supporting statement (backing) summarizing a related set of Data ***in support of a claim.*** Evidence is specific to the context in which the Data were collected. It describes a **contextualized relationship** between two properties, a property and a consequence of that property, or a finding, rather than a general principle or law.
		Rule	A supporting statement (backing) describing a **generalized relationship**, principle, or law ***in support of a claim.*** This relationship is general in the sense that it is expected to hold even in contexts and circumstances not previously observed.

To create units of analysis within a section of transcribed discussion, coders should begin by identifying all instances of claims, premises, and backing. Then, to identify each new reasoning unit, the coder should look for changes in the claim, premise, or both. To facilitate this process, the coder can refer to the ‘claim-premise decision chart,’ shown in Table 3.

Table 3. *Claim-premise decision chart.*

Claim	*Premise*	*Unit*
Same	Same	Same
Same	Different	Different
Different	Different	Different
Different	Same	Different

While these elements of reasoning are usually stated explicitly in writing, when analyzing classroom talk, we found many instances of implicit claims that were known to all participants in the discussion as a result of being a part of the ongoing ‘social text’ (Aulls, 1998). Take, for example, the excerpt of transcript shown in Table 4 below, in which a premise is stated explicitly in the first line, and then referred to implicitly in the following two speaking turns by two different students.

Table 4. *Example transcript excerpt with implicit premise and two reasoning units.*

Reasoning Unit	Elements of Reasoning	Transcript (Elements of Reasoning underlined)
1	Premise (new)	Teacher: What is it then with a piece of wood with holes?
	Premise (same, implicit) Claim (new)	Student 1: That floats.
2	Premise (same, implicit) Claim (different)	Student 2: No, it will sink.

In this excerpt, the first reasoning unit contains an explicit reference to a premise by the teacher, and the following statement by the student that contains a claim in reference to the implicit premise. The reasoning unit changes with the next student statement, which again refers to the implicit premise, but makes a new claim (the wood will sink).

We found it helpful during the process of identifying claims, premises, and backing, to write a storyline that puts together the co-constructed statements from the teacher and student that are relevant to the ongoing process of reasoning in simpler form. The purpose of the storyline is to interpret the content of reasoning, not the structure, and serves the purpose of determining what the teacher and students have said as it relates to the reasoning prior to coding. More simply, the process of writing the storyline determines the ‘official’ interpretation of the ongoing conversation.

Once the reasoning units in the entire transcript have been identified, the coders may proceed to apply the three relevant sets of codes to the unit: Quality of reasoning, teacher support of reasoning, and conceptual level of reasoning.

Quality of Reasoning Codes

Based on our review of the literature, we established that much of the reasoning in science classroom discourse to has been found to be low quality of reasoning lacking. We therefore realized that we would need to develop intermediate levels along a continuum between high-quality reasoning, as measured by the presence of a complete reasoning structure similar to that shown in Figure 1, and unsubstantiated claims. To do so we draw parallels between the levels of reasoning identified by Driver et al. (1994) and Carey et al. (1989).

On this continuum, the least sophisticated discourse is conceptualized to consist of single claim(s) without any backing (*unsupported reasoning)*. This type of reasoning may also include circular or tautological statements as backing (e.g., the rock sinks because it sinks), or meaningless statements (e.g., the rock sinks because it wants to sink). Partial reasoning structures rely on data or evidence only. Those structures that reference only data or specific phenomena (*phenomenological reasoning)* as backing for a claim rely on single observations by students (e.g. the rock sinks because I saw it sink) or single properties (e.g. the rock sinks because it's heavy). More sophisticated reasoning is backed by evidence (*relational reasoning)* in the form of comparisons between properties (e.g. the rock sinks because its mass is greater than its displaced volume) or are summaries or datapoints (e.g., the rock will sink because in our test every rock sank).The most sophisticated reasoning is conceptualized by the full model of scientific reasoning shown in Figure 1, consisting of claims about phenomena that are supported by a generalizable statement about relationships between properties (or a rule); we call this *rule-based reasoning*. In addition to this statement of a rule, (empirical) backing such as reference to data collection may be used as backing.

These four levels of reasoning are further explicated in Table 5.

Table 5. *Quality of Reasoning in Science Classroom Discourse.*

Quality of Reasoning	Definition	Description	Diagram
Unsupported	No reasoning	Elements of reasoning present, but no processes of reasoning; pseudo, circular, or tautological reasoning	Premise ← → Claim
Phenomenological	Data-based reasoning	Data applied to a claim	Premise ← → Claim ↑ Data
Relational	Evidence-based reasoning	Evidence applied to a claim, including analysis of data	Premise ← → Claim ↑ Evidence ↑ (Data)

Rule-Based	Inductive or deductive rule-based reasoning	1. Deductive reasoning (top-down), applying a rule to make a claim with respect to a new premise 2. Inductive reasoning from data to rule 3. Applying a rule with new evidence (exemplifying with analogy) 4. Complete reasoning structure (whole framework)	Premise ← → Claim ↑ Rule ↑ (Evidence) ↑ (Data)

The quality of reasoning codes combine the components and processes elements of the model of scientific reasoning. The table above also illustrates that in certain types of reasoning, explicit reference to all three types of backing are not necessary to be coded at a particular level. For example, we consider a claim and premise, backed by a rule, as an incidence of rule-based reasoning, rather than expecting students to go through the entire data to evidence to rule transformation in support of a premise and claim.

Teacher Contribution to Reasoning

Since the discourse that occurs in science classrooms is to a certain degree supported and, in some cases, supplied by the teacher, we have a second set of codes that indicate the extent to which the teacher supports a particular reasoning unit. To that end, the framework includes codes for the teacher’s contribution to each reasoning unit, in terms of which elements of reasoning the teacher prompted, and which elements did the teacher provide.

The teacher contribution to reasoning is coded according to the function of teacher statements in each reasoning unit, i.e. the extent to which teachers prompt for or provide elements of reasoning. Every component of reasoning (data, premise, data, evidence, or rule) that was either contributed (provided) or prompted (solicited) by the teacher is given a code within the reasoning unit; each code is applied only once. The different codes and examples are provided in Table 6.

Table 6. *Teacher Contribution to Reasoning Codes*

Codes	Description	Subcodes and Examples
Prompting for elements of reasoning	Teacher uses questions or prompts (statements, experimental settings) for students to provide elements of reasoning .	Prompting for elements Premise Can you give me another example? Claim How much water does a ship like this one displace? Backing (General) Why do you think that? How can you support that? Show us once more. Backing (Specific) Rule Can you put this in more general terms? Evidence Do you notice a similarity between the wax cube and the stone cube? Data Claim: this stone will sink. Prompt: show us.
Doing/Providing elements of reasoning	Teacher provides elements of reasoning for students in the sense of knowledge-generation coming from the teacher	Any instance in which an element of reasoning is first provided by the teacher instead of a student

Once an entire reasoning unit has been coded for teacher support, these codes combined with the quality of reasoning codes indicate the extent to which reasoning was provided or supported by the teacher. For example, if reasoning unit coded as featuring ‘rule-based’ reasoning where the teacher provided a premise and claim and then prompted for a rule is quite different than a unit in which the students had provided all elements.

Conceptual Understanding

We acknowledge the important link between quality of reasoning and students' conceptual understanding. The final set of codes is thus intended to identify the conceptual underpinnings of the reasoning that takes place in whole-class discussions. Since our research collaboration involved a number of datasets all dealing with sinking and floating, our instrument also includes a set of codes that constitute many of the different ideas about sinking and floating from the literature and our own observation (e.g. Piaget & Inhelder, 1942/1974; C. Smith, Carey, & Wiser, 1985; C. Smith, Snir, & Grosslight, 1992; E. L. Smith, Blakeslee, & Anderson, 1993). These ideas go beyond a collection of reasons for sinking and floating based on intuitive reasoning as supported by basic knowledge elements originating in everyday experience (e.g. diSessa's (1993) p-prims), and as well as non-intuitive concepts that develop through science instruction (Table 7).

Table 7. *Common student understandings about sinking and floating.*

Concept	***Example***
Personal experience	'my uncle went to Hawaii and he said it's easier to float in saltwater' 'It floats because I have tried it out'
Shape (holes, flatness)	'The wooden board will sink because it has holes'
Active air	'The tree trunk floats because the air in it wants to rise'
Hollowness (containment of air)	'The egg floats…because it's got – all eggs have like an air cell.'
Weight / mass	'More mass, more sinking'
Size / volume	'The tree trunk will sink because it is so large'
Water supports	'The tree trunk floats because it is pushed up by water'
Heft / qualitative notion of volume relative to mass	'It will sink because it is compact' 'It feels heavy for its size'
Material	'Wood floats'

	‘Rocks sink’
Taking up space	‘It will float because it takes up a lot of space’
Mass with volume controlled	‘If the volume is the same, the object with more mass will sink’
Volume with mass controlled	‘The larger bottle has a larger volume than the smaller bottle with the same amount of mass’
Relationship of volume and mass	‘The mass of the object is pretty close to the displaced volume’
Qualitative comparisons with water	‘Things that are lighter than water will float’
Relation of volume to water displacement	‘The larger something is, the more water it will displace’
Density	‘If it isn’t very dense, it floats’
Relative density	‘If the density of the object is greater than the liquid, it will sink’
Buoyancy force	‘It floats because it has buoyancy’
	‘It floats because the water pushes it up’
Buoyancy force relative to weight	‘Gravity pulls the boat down. The water pushes it up, but the water wins’

Although these conceptual understanding codes were originally intended to be hierarchical following some kind of empirically validated progression of student understanding, we learned through the course of our collaboration that the two curricula we had been analyzing were based on different progressions of student understanding. For example, the concept of hollowness (containing air) was considered an intermediate level explanation of floating and sinking in the elementary school curricula, whereas it was rated as a naïve conception in the secondary school curricula. Therefore, conceptual codes should be applied not only according to available research results on student conceptual development within the investigated domain, but should also take into account the way in which particular curricula reinforce and order particular explanations in different stages of the curriculum.

The Instrument in Action: Example of Coded Classroom Discourse

Taken together, the sets of codes in the *Reasoning in Science Classroom Discourse* instrument provide information on the quality of reasoning in the classroom, the extent to which that reasoning is supported by the teacher or is performed by students independently, and the extent to which different claims and premises are begin negotiated in the course of the reasoning. Table 8 presents a sample of a coded transcript to illustrate how the instrument is used. This sample transcript is taken from a third-grade classroom in Germany.

Table 8. *Example of a coded transcript.*

	Elements of Reasoning	Storyline	Dialogue	Teacher Contribution to Reasoning	Quality of Reasoning	Conceptual level	*Coding Notes*
Reasoning Unit 1							
1.	Premise 1 Claim 1	Teacher puts two different objects into water; one sinks and the other one (wax cube) floats	T: Now I am doing the same procedure in water: I am dropping them in the water. *[Teacher drops objects in water.]* Why did this happen? Do you have any idea?	Provides premise Prompts for backing (general)			*Elements of reasoning that appear for the first time in the transcript are given credit to the original speaker; here, the teacher*
2.			[*Some students make suggestions*]				
3.	Backing (Evidence 1)	[wax cube] (floats) because it weighs less than water	S: because the wax is lighter than water			Qualitative comparisons with water	*Student backs up reasoning based on mass only; two codes given (primary/secondary)*
4.		Give a more precise explanation	T: Give a more precise explanation.	(repeating/communicative support)			
5.	Backing (Evidence 1)	[wax cube] (floats) because it weighs less than water	S: Yes, because of that it floats above, because it is just lighter than water.			Qualitative comparison with water	*Same as turn 3*

	Elements of Reasoning	Storyline	Dialogue	Teacher Contribution to Reasoning	Quality of Reasoning	Conceptual level	*Coding Notes*
6.			S: (some students cross talking, one student says “heavier”, an other student is talking of “the same amount”)				
7.	Backing (Evidence 1)	[wax cube] (floats) because it is lighter than water How much?	T: One at a time. Well, you think, it has to be lighter than water and then it will float. And now Christian has asked: “how much?”			Qualitative comparison with water	*Same as turns 3 & 5* *Teacher is <u>not</u> coded as providing evidence because student said it first, and teacher is only repeating (that is, the evidence was originally provided by the <u>student</u>)*
8.		[wax cube] (floats) because it is one drop lighter than water	S: so, one drop.				
9.			S: even such a cube filled with water				

	Elements of Reasoning	Storyline	Dialogue	Teacher Contribution to Reasoning	Quality of Reasoning	Conceptual level	*Coding Notes*
10.	Backing (Evidence 2)	[wax cube] (floats) because a cube of water weighs more than a cube of wax	S: And actually, the water is barely heavier than this, than the wax cube, and therefore the wax cube floats on the surface.		Level 3	Relationship of volume and mass	*Statement made more specific and is now comparing mass of two substances (water, wax) when volume is held constant*
11.		How do you know?	T: How did you get that?	Prompt for backing (general)			*Teacher asks student to support his/her reasoning by asking <u>how</u> question*
12.	Backing (Data 1)	Through the questionnaire (pretest)	S: by the questionnaire (pretest)				
13.	Backing (Evidence 2)	[wax cube] Through the questionnaire (pretest) you know that (the wax cube) is lighter than the same amount of water	T: you did hit on that by the questionnaire, that this is lighter than the same amount of water. Marcus, do you have the same idea? Yes. You have developed the idea thereby? This is exactly the idea I would like to test with you now.	(repeating/communicative support)		Relationship of volume and mass	*At end of reasoning unit, summary judgment is made based upon the quality of the backing provided. This unit includes several pieces of evidence and one piece of data to support the original claim; therefore, it is coded as Level 3 reasoning.*
Reasoning Unit 2							

	Elements of Reasoning	Storyline	Dialogue	Teacher Contribution to Reasoning	Quality of Reasoning	Conceptual level	*Coding Notes*
	Premise 2	[wooden board with holes] What is with a wooden board with holes?	T: Whether it could work as you said. But first I have some other questions to that. What happens with a wooden board with holes?	Provides premise Prompts for claim	Level 1		*Teacher is credited for providing a new premise. She asks what will happen to this new premise, so it is coded as prompting for a claim*
14.	Claim 2	[wooden board with holes] floats	S: it will float				*Unit included only a claim and premise, so is coded as level 1 reasoning*
Reasoning Unit 3							
15.	Claim 3	[wooden board with holes] sinks	S: No, it will sink		Level 1		*Unit included only a claim and (implicit) premise, so is coded as level 1 reasoning*
Reasoning Unit 4							
16.	Claim 2	[wooden board with holes] floats. Why?	T: Do you think that it will float? Why?	Prompts for backing (general)	Level 3		*Teacher asks student(s) to explain why the wooden board with holes will sink.*

	Elements of Reasoning	Storyline	Dialogue	Teacher Contribution to Reasoning	Quality of Reasoning	Conceptual level	*Coding Notes*
17.	Backing (Evidence 3)	[wooden board with holes] floats. it weighs less than water, it has holes	S: because it is lighter than water because there are holes inside			Shape Weight/mass	*Student relates two pieces of data to each other as evidence. Primary level conceptual code is 'unproductive misconception', but secondary level gives it two codes – one for mass, and the other for holes (alternative conception).*

The codes applied to the preceding transcript are summarized in Table 9 below.

Table 9. *Summary of codes from example transcript by reasoning unit*

Unit	Reasoning Level	Teacher Contribution to Reasoning	Conceptual Codes
1	3	Provides premise Prompts for backing (general) (2x)	Qualitative comparisons with water Relationship of volume and mass
2	1	Provides premise Prompts for claim	n/a
3	1	Not applicable	n/a
4	3	Prompts for backing (general)	Shape Weight/ mass

In the exchange presented in Table 8, the teacher presents students with two objects, thereby providing students with the premise about which they are to reason. She then prompts for the students to provide backing. In response, a student provides a claim based on a comparison of the mass of the object to water and, with additional support from the teacher, the students are able to provide evidence in support of that claim and with a more advanced level of conceptual sophistication. In the next reasoning unit, the teacher provides a new premise (a piece of wood with holes in it) and asks for claims, and is met with two disagreeing students. The teacher asks only one of those students to support her claim, and is provided with evidence in the form of a comparison of the mass of water and the board.

In this exchange, the *Reasoning* framework provides us with information about the quality of backing provided for the different claims advanced. We see that students only provided evidence (i.e., Level 3 reasoning) when prompted to do so by the teacher, and when not, made unsubstantiated claims. We also see that students may have been reasoning at a relatively high level, but were basing their reasoning on what might be considered insufficient conceptual underpinnings (dependent upon the curriculum in use).

Despite the information that the *Reasoning* framework is able to capture, our approach does, like any analytic lens, focus on some aspects of classroom reasoning at the expense of others. For example, the codes applied to the exchange in Table 8 above do not capture the disagreement that arises between the students regarding what the piece of wood with holes in it would do. In this sense, while the instrument captures the quality and conceptual underpinnings of the reasoning happening in this excerpt, it does not capture the extent to which competing ideas are juxtaposed, and if they were or were not resolved.

In addition, there is an unclear and potentially low correspondence between quality of reasoning (as designed by this framework) and the conceptual richness of the discourse. We distinguish here between conceptual level, a performance metric defined in terms of curriculum learning goals, and conceptual richness, a characteristic of the learning process itself. A conceptually rich discourse involves students in active conceptualization and sense making. In the example protocol, reasoning unit and reasoning unit 4 are both described as being level-3 reasoning. Yet in the first reasoning unit, the student engages in a richer process of conceptualization, making the intensive aspect of "lighter and heavier" more explicit as he/she progresses through the discourse. Reasoning unit 4, by contrast, shows no such progress.

We expect, in science inquiry, that conceptually rich discourse will involve a high level of argumentation. Yet the reverse is not necessarily true; that is, a discourse might encompass frequent appeals and references to evidence and yet be quite bereft of the active sense making that we value in the inquiry process. Thus the *Reasoning* framework cannot stand on its own as a measure of the overall quality of scientific reasoning.

Science reasoning does not begin with bare facts but with theory-dependent observational statements. We might present students with evidence, but they necessarily interpret it for themselves. The *Reasoning* framework does not address such interpretation, which can be crucial to conceptual progress. Consider, for instance, reasoning unit 1. In turn 5, the student says that the wax "floats above" to support his/her claim that the wax is "just lighter than water." In turn 10, he/she says that "it floats on the surface" in relation to the claim that the water is barely heavier than the wax cube. Floating above and floating on the surface are arguably two different observational statements. In the second case, there is a more precise interpretation. If we take this second statement to mean that only some very small portion of the wax protrudes above the surface of the water, then we can begin to distinguish conceptual advancement.

Discussion

This paper has presented the foundations of the instrument *Reasoning in Science Classroom Discourse* and has explained how it may be applied to transcripts of whole-class discussions. Empirical analyses based on the application of this instrument to specific research questions will be included in the following paper in this symposium. However, the presentation of the instrument in this paper already raises issues for consideration in these analyses. Our highest level of reasoning included inductive and deductive reasoning, but we do not distinguish between the two; the framework could be revised to include epistemic categories similar to Jimenez-Alexandre et al. (2000). Future iterations of the framework may also involve an additional set of codes that can capture the extent to which actual *argumentation* is taking place between students (Osborne, Erduran, & Simon, 2004). In addition, going beyond simple frequencies based on the codes by mapping arguments based on the elements of reasoning and using a symbology similar to that employed by Resnick et al. (1993) could make other aspects of reasoning explicit that are obfuscated by the *Reasoning* framework. Future studies should continue to modify the framework as it is applied to other datasets to help us develop a further understanding for how reasoning can be supported in science classrooms.

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Purpose of the Instrument

The framework is intended for use on portions of classroom discussion where reasoning about science phenomena is *expected* to happen. The instrument captures teachers’ and students’ co-constructed reasoning about science phenomena and the degree (quality?) to which claims are being backed up. On a continuum of reasoning, the most sophisticated science discourse is conceptualized to consist of claims about science phenomena which are backed up with a generalizable statement about relationships between properties (or a rule). In addition to this statement of a rule, (empirical) backing such as reference to data collection may be used as backing. In contrast, the least sophisticated science discourse is conceptualized to consist of single claim(s) without any backing.

In coding each reasoning unit, elements of reasoning are identified which are determined by their function in the conversational flow and which are classified as either claims about science phenomena or backings of claims. From the combination of elements of reasoning in each reasoning unit we can determine the quality of reasoning which addresses the extent to which claims are backed up with data, evidence, and rules. Coding the teacher contribution in each reasoning unit, a relation between level of reasoning and the extent to which teachers prompted for elements of reasoning or provided these themselves can be identified. Finally, coding the conceptual sophistication within each reasoning unit allows the identification of co-occurance of levels of reasoning with certain concepts addressed in the curriculum.

Overview: Videotape Coding Framework: “Reasoning in Science Classroom Discourse”

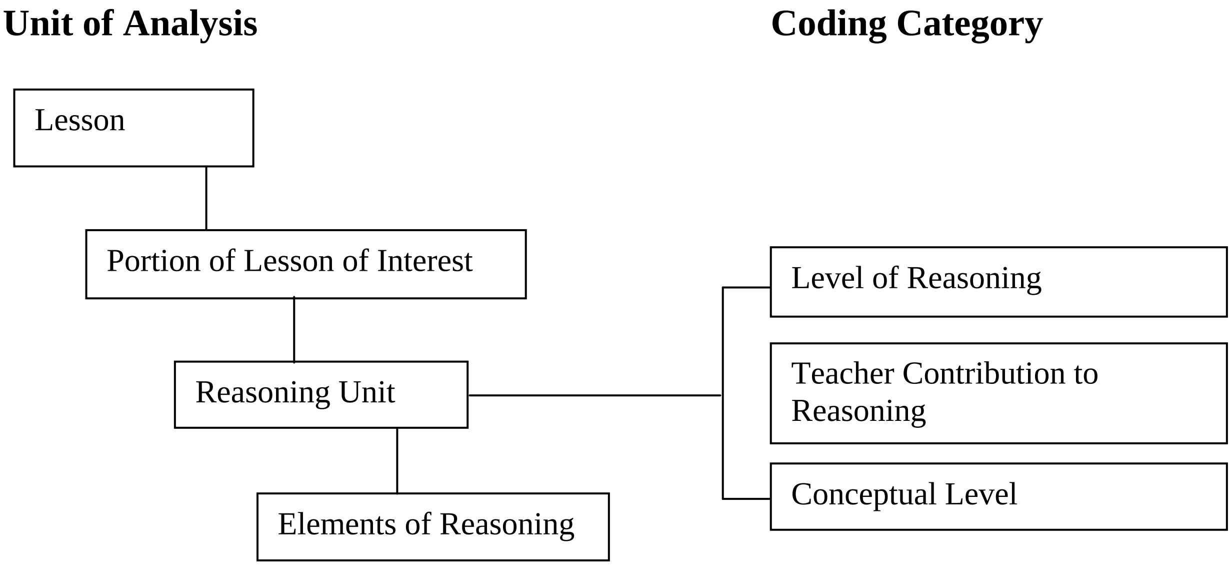


Table of Codes

Category	Code	Variable	Sub-Code
Data Markers	Teacher	TEACH	-
	Lesson	LESSON	-
	Reasoning Unit	RU	-
	Time	TIME	-
Elements of Reasoning	Premise	PREM	-
	Claim	CLAIM	-
	Data	DATA	-
	Evidence	EVID	-
	Rule	RULE	-
Quality of Reasoning	Unsupported	QOR_1	-
	Phenomenological	QOR_2	-
	Relational	QOR_3	-
	Rule-Based	QOR_4	-
Teacher Contribution to Reasoning	Prompting for Elements of Reasoning	TPMT_P	Premise
		TPMT_C	Claim
		TPMT_G	Backing (general)
		TPMT_D	Backing (data)
		TPMT_E	Backing (evidence)
		TPMT_R	Backing (rule)
	Doing/Providing Elements of Reasoning	TPRO_P	Premise
		TPRO_C	Claim
		TPRO_D	Data
		TPRO_E	Evidence
		TPRO_R	Rule
	Communicative Support	TPRO_CS	-
Conceptual Level	Other experience	CON_O	Correct/Incorrect
	Alternative Conceptions	CON_AC	Correct/Incorrect
	Naïve Science Conceptions	CON_NSC	Correct/Incorrect
	Mass OR Volume	CON_MV	Correct/Incorrect
	Mass AND Volume	CON_MAV	Correct/Incorrect
	Density	CON_D	Correct/Incorrect
	Relative Density	CON_RD	Correct/Incorrect

Definition and Description of Categories

Elements of reasoning

The elements of reasoning (premise, claim, data, evidence, rule) describe basic functions of statements by teachers and students within classroom discourse about science phenomena. Statements are classified as either claims or backings of claims (i.e., data, evidence, or rule). The identification of claims and the extent to which these claims are backed up then allows the coding of the quality of reasoning within each reasoning unit.

Elements of Storyline	**Elements of Reasoning (General)**	**Elements of Reasoning (Specific)**	**Description/Definition**	**Hints**
Premise	Premise	Premise	A statement describing the relevant characteristics or properties of the object about which the Claim is made (i.e., the conditions for the claim). The Premise is the “given” information from whence the Claim is derived upon. premise: object, state of an object, general expression (“subject of reasoning”), point of reference	A premise is only being coded if reasoning is going on with it. Standard cubes Ship: sinking ship, iron ship, immerged ship, ship with a cover
Claim	Claim	Claim	A claim about a specific premise. This includes either what something will do in the future (prediction/ presumption), or is happening in the present or past (conclusion or outcome). A claim could be expressed as a relationship among datapoints (evidence), statements about single datapoints (data), and statements of generalized relationships (rules); however, it is an ***isolated*** statement which is not used as backing.	This Styrofoam cube is the lightest. (not used as backing) This cube has a density smaller than water (not used as backing)
	Backing	Data	A supporting claim (backing) describing the outcome of a single specific experiment or a single observation in a personal anecdote or prior knowledge / books / tests ***in support of another claim***.	*Usually* personal anecdotes will be data (conservative approach), e.g., it sinks because I read it in a bock If a student uses as backing something that comes from a book (or, for example, a pretest or questionnaire), code as “data.” Code claim as ‘data’, if all questions are answered with ‘yes’: - does claim refer to specific objects / states? - is it a statement of a single data point? (no relationship!) - does it describe a specific property? - is it used to back up or support a prior related claim?
		Evidence	A supporting claim (backing) summarizing a related set of Data ***in support of another claim.*** Evidence is specific to the context in which the Data were collected. It describes a **contextualized relationship** between two properties, a property and a consequence of that property, or a finding, rather than a general principle or law.	Code claim as ‘evidence’, if all questions are answered with ‘yes’: - does claim refer to specific objects / states? - is it a statement of a relationship? - is it used to back up or support a prior related claim?
		Rule	A supporting claim (backing) describing a **generalized relationship**, principle, or law ***in support of another claim.*** This relationship is general in the sense that it is expected to hold even in contexts and circumstances not previously observed.	rule: its floats because everything lighter than water will float; I know this from the questionnaire Code claim as ‘rule’, if all questions are answered with ‘yes’ – Is it a general expression? – Is it a statement of a relationship? – is it used to back up or support a prior related claim?

Rules for assigning elements of reasoning

Usage Rule: Apply to every premise/ claim / assertion within storyline

- In coding the elements, claims become either claims, data, evidence, or rule. Claims that are *used as* backing are coded as evidence, data, or rule.

Premise

- a premise is the subject of reasoning and needs to occur with a claim
- a change of premise occurs if the subject of reasoning changes,
  e.g., wooden board with holes, ship with holes (close in content)
  ship, immerged ship (different state of object)
  wax cube, ship (entirely new content)

Claim

- Definition of different claims:
  a different claim is coded if it incorporates content that has not been stated in a previous claim (red line = begin of a new unit)
- The A B C chart should be used as a rule if a claim is being modified:

	Regular Case	**Cases of modified claims**			
	Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 5**
Claim	A	AB	AB	AB	A
Different claim	B	C	BC	ABC	AB
Different claim	C				

Examples

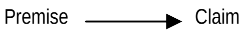
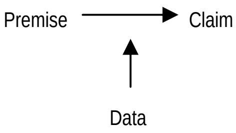
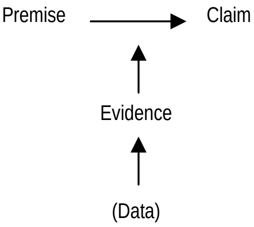
	A It is heavy	AB It is heavy and has holes	AB It is heavy and has holes	AB It is heavy and has holes	A It is heavy
	B It has holes	C It is big	BC It has holes and is big	ABC It is heavy and has holes and is big	AB It is heavy and has holes
	C It is big				

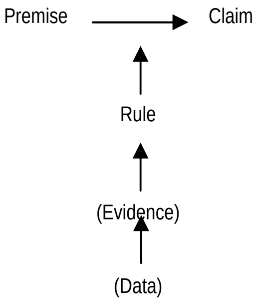
- Conservative approach to ambiguous statements: code rather a different claim than a possible backing

Quality of reasoning

The quality of reasoning is coded on one of four levels of increasing sophistication (unsupported, phenomenological, relational, rule-based). The four levels differ in the extent to which claims in science discourse are being backed up by data, evidence, or rules, i.e., they allow inferences about the way empirical data and other experience is used by teachers and students when reasoning about science phenomena.

Within each reasoning unit, identify which elements of reasoning are present and assign level of reasoning correspondingly, regardless of how often an element appears. Elements of lower levels (e.g., data, evidence) appearing in parantheses need not be present in the reasoning unit.

Level	Definition	Description	Structure Diagram	Example
1 **Unsupported**	No reasoning	Elements of reasoning present, but no processes of reasoning; or pseudo, circular, or tautological reasoning		**Elementary school** T: What about a wooden board with holes? S: It will sink.
2 **Phenomenological**	Data-based reasoning	Data applied to make a claim, but no analysis of data, no interpretation of evidence, no application of a rule		**Secondary school** T: Those of you who thought the small, white block, number one, is going to sink, why did you say that? Taylor? S: Because it's small and compact. **Secondary school** T: If something has holes in it, it might sink. What's the evidence that that may be true? (…) S: If you had a bottle or something (..) something that and there's a hole in it and water would fill up with it and it could sink more because T: so like a bottle with a hole in it? S: yeah.
3 **Relational**	Evidence-based reasoning	Evidence applied to a claim, including analysis of data, but without interpretation into a rule. (includes analogies)		**Secondary school** T: Why did you think it will float? S: Because it's the same density as the other one. **Elementary school** T: Sara-Lena, have you got the wax cube? All the kids had one. What was it we thought, that it would float or that it wouldn't? S: That it would float. T: Hmm [yes]. Pardon? S: I said it would float. T: Why did you think it would float? S: Because I – well, seeing that the candle floats, I thought that the piece of wax would float, too. T: Aha. Hmm [yes]. Ok, so, what you said was: The candle floats, so the wax must float, too. That's good reasoning.

4	**Rule-Based**	Inductive or deductive rule-based reasoning	Three possible ways: 5. Deductive reasoning (top-down), applying a rule to make a claim with respect to a new premise 6. applying a rule with new evidence (exemplifying with analogy) 7. Complete reasoning structure (whole framework), also inductive reasoning from data to rule		**Constructed Example** T: Why did you think it will float? S: Because everything that is heavier than the same amount of water sinks. And this block weights less than the same amount of water **Constructed Example** L. Weißt du auch, was mit dem Plastikwürfel passiert? 63 g, Niklas? Niklas: der schwimmt. S: nein L. Warum? Niklas: also, weil *alle Dinge, die leichter sind als die gleiche Menge Wasser schwimmen, und* die gleiche Menge Wasser ist ja schwerer *als der Plastikwürfel.* T: Do you know what happens with the plastic cube? 63 g, Niclas? Niclas: it floats S: No T: Why? Niclas: because *all things that are lighter than the same amount of water float and* the same amount of water is heavier *than the plastic cube.* **Elementary school** S1: Ahm, if you, ahm, try this with the cubes and the wheel (Draht), it's the same for both of them. They will all replace the same amount of water. L: Go ahead, show us once more. S1: (steps into the circle) Ok, if I take this one. If I take the cork cube [managment time] S: Yes, that's it (second child steps into the circle, takes hold of the cube; the other child makes a mark on the glass jar). S1: Ok. And now for the stone cube. The water goes up at once. T: It's rising as high as with the wax cube. [management time] S1: (takes another cube) It's rising as high. S: Ah ha. L: Super. S1: They are all the same size. It's not the weight that counts, it's the size.

Teacher Contribution to Reasoning

The teacher contribution to reasoning is coded according to the function of teacher statements in each reasoning unit, i.e. the extent to which teachers prompt for or provide elements of reasoning, or else provide (minimal) communicative support for student reasoning.
Code every teacher statement within a reasoning unit. Every code is just given once (appear/not appear) within one reasoning unit.

Codes	Description	Rule	Examples
Prompting for elements of reasoning	teacher uses questions or prompts (statements, experimental settings) for students to provide elements of reasoning **Subcodes** claim, premise, backing in support of a claim (general), specific backing in support of a claim (data, evidence, or rule) .	Prompts can include the restatement of prior claims (including student claims) Note: teacher statement that asks students to provide "evidence" need not necessarily be coded as prompting for evidence	**Prompting for elements** **Premise** Can you give me another example? **Claim** How much water does a ship like this one displace? **Backing (General)** Why do you think that? How can you support that? Show us once more. **Backing (Specific)** *Rule* Can you put this in more general terms? *Evidence* Do you notice a similarity between the wax cube and the stone cube? *Data* Claim: this stone will sink. Prompt: show us.
Doing/Providing elements of reasoning	Teacher provides elements of reasoning for students in the sense of knowledge-generation coming from the teacher **Subcodes** premise, claim, rule, evidence, data	The person who generated the content gets credit for it.	
(Optional: Repeating / Communicative support)	Teacher is involved in the reasoning unit, but only provides communicative support either by repeating student elements of reasoning or by other encouragement	Applied only when the teacher repeats what the student said within the same reasoning unit; otherwise it is providing!	

Conceptual sophistication/Level

The code of conceptual sophistication captures the concepts addressed in each unit of reasoning (which may be ordered from low to high sophistication according to each curriculum) as well as whether these concepts were applied correctly.
Score whether concept was there and whether it was used correctly (see definitions for concepts #.#). According to the level system of each project site the concepts can then be assigned to a specific level of conceptual sophistication.

Germany – Primary Level Coding System

Level		Description
1	Unproductive Misconception	Concepts which need to be restructured or given up (will not hold when tested)
2	Prescientific Conceptions	Concepts which are useful in everyday life and which may be differentiated or integrated into level 3 concepts
3	Scientific Conceptions	

US – Secondary Level Coding System

Level		Description
0	Other experience	Personal experience that does not belong to other factors
1	Alternative Conceptions	Misconceptions
2	Naïve Science Conceptions	Pre-scientific explanations that are not entirely correct
3	Mass OR Volume	Explanation featuring mass OR volume, but not in comparison to each other
4	Mass AND Volume	Direct, explicit comparison of mass to volume
5	Density	Explanation based only on the property of density
6	Relative Density	Comparison of density of object to density of medium
B	Buoyancy	Mentions buoyancy in explanation

Germany – Primary Level	Concepts	US – Secondary Level
Unproductive Misconceptions	Other feature (e.g., motor of ship)	Other Experience
	Personal experience	Other Experience
	Shape (holes, flatness)	Alternative Conception
	Active air	Alternative Conception
	Hollowness (containment of air)	Alternative Conception
	Weight / mass	Mass OR Volume
	Size / volume	Mass OR Volume
Prescientific Conceptions	Water supports	Naïve Conception
	Heft / qualitative notion of volume relative to mass	Naïve Conception
	Material	Naïve Conception
	Taking up space	Mass OR Volume
	Mass with volume controlled	Mass AND Volume
	Volume with mass controlled	Mass AND Volume
	Relationship of volume and mass	Mass AND Volume
	Qualitative comparisons with water (lighter than water)	Mass AND Volume
Scientific Conceptions	Relation of Volume to Water displacement	Mass AND Volume
	Density	Density
	Relative density	Relative Density
	Buoyancy force	Buoyancy – Naïve Conception
	Buoyancy force relative to weight	Buoyancy – Naïve Conception

Examples of Concepts:

Other feature (e.g., motor of ship)	

Concept	***Example***
Personal experience	‘my uncle went to Hawaii and he said it’s easier to float in saltwater’
	‘It floats because I have tried it out’
Shape (holes, flatness)	‘The wooden board will sink because it has holes’
Active air	‘The tree trunk floats because the air in it wants to rise’
Hollowness (containment of air)	‘The egg floats…because it’s got – all eggs have like an air cell.’
Weight / mass	‘More mass, more sinking’
Size / volume	‘The tree trunk will sink because it is so large’
Water supports	‘The tree trunk floats because it is pushed up by water’
Heft / qualitative notion of volume relative to mass	‘It will sink because it is compact’
	‘It feels heavy for its size’
Material	‘Wood floats’
	‘Rocks sink’
Taking up space	‘It will float because it takes up a lot of space’
Mass with volume controlled	‘If the volume is the same, the object with more mass will sink’
Volume with mass controlled	‘The larger bottle has a larger volume than the smaller bottle with the same amount of mass’
Relationship of volume and mass	‘The mass of the object is pretty close to the displaced volume’
Qualitative comparisons with water	‘Things that are lighter than water will float’
Relation of volume to water displacement	‘The larger something is, the more water it will displace’
Density	‘If it isn’t very dense, it floats’
Relative density	‘If the density of the object is greater than the liquid, it will sink’
Buoyancy force	‘It floats because it has buoyancy’
	‘It floats because the water pushes it up’
Buoyancy force relative to weight	‘Gravity pulls the boat down. The water pushes it up, but the water wins’

Guidelines for coding and establishing units of analysis

Overall procedure

1. Prior to coding, it is important that the coders watch the videotapes so that they are aware of what has happened within the lesson as a whole so that the context of the reasoning is known.
2. Write a *storyline* that puts together the co-constructed statements from the teacher and student that are relevant to the ongoing process of reasoning in simpler form (see 0).
3. Code the elements of reasoning (see 0).
4. Follow the 'claim-premise decision chart' to identify new reasoning units (see 0).
5. Apply codes for level of reasoning (0), teacher role (0), and conceptual level (0) to every reasoning unit.

Storyline

The purpose of the storyline is to interpret the content, not the structure, and serves the purpose of determining what has been said by the teacher and students as it relates to the reasoning.

1. Sometimes this will involve restating what has been said, sometimes deciding what to skip, others deciding/interpreting so we know how to interpret what has been said.
2. This is done by marking all premises (yellow) and claims (green).
3. Indicate what the teacher/students are talking about in each row by writing or repeating the premise and marking it with brackets. This helps the coder be clear about the subject of reasoning. For clarity, use the same terms for describing each statement each time it is mentioned.
4. If a teacher or student statement is not completely audible, be sure to make a note in the storyline that it is inaudible and should be ignored.
5. The storyline should include references to previous statements from the discussion. These implicit statements should be identified by placing them in parentheses.

   Example:

Storyline	Discourse
[Styrofoam] Is it lighter or heavier (than the water cube?)	T: „Genau, das schwimmt. Und ist Styropor leichter oder schwerer?“

6. If during the classroom discourse data collection / observation / execution of experiments is going on, summarize in a claim the essence of what students could observe. Do not account in the story line for all of the comments that students and teacher may make as they observe and do the experiments.

   Example:

Note: this storyline summarizes what students did and observed when doing an experiment about water displacement

[the standard cubes] All cubes displace the same amou water	S1: Ahm, if you, ahm, try this with the cubes and and the wire; it’s the same for both of them. They will all replace the same amount of water.
	T: Go ahead, show us once more.
[the cork cube]	S: (steps into the circle) Ok, if I take this one. If I take the cork cube (tape around the cube slips off, hilarity). It always slips off.
	T: Wait a moment, you’d better use this jar, it’s easier for us to see (steps into the circle, sits down again).
	S: So if I put this one into the water (tape slips off again, hilarity).
	S: It’s gone again.
	S: Take this one, this one is better.
[the wax cube]	T: stubborn cork cube. But the wax, now, that will be alright.
	S: Make a mark.
	T: Give me a pen.
	S: Let go.
	S: Press it down to the bottom.
	S: Down to the bottom.
	S: Wait.
[the wax cube] If you press it down, it makes the water level rise.	S: Yes, that’s it (second child steps into the circle, takes hold of the cube; the other child makes a mark on the glass jar).

- Find out the central point of reference for ongoing and following reasoning; not all of the objects mentioned in discourse should be coded as premises
- Pay attention to changes in qualifiers; a new *qualifier* signifies a new premise. e.g., a ship, a *metal* ship, a ship *with holes*, a *submerged* ship.

- Similarly, only spell out pronouns (e.g. der/die/das, it/that) referring to the central point of reference in the story line (not all of the pronouns should be spelled out).

Example:

[the plastic form] has the same size as one of the cubes.	L: Ja, so passt das ziemlich genau. Ich darf es auch nicht ganz reinstecken, weil ich es sonst nicht rauskriege, ne. Also es ist genauso groß wie so ein Würfel.

→ only the „it“ of the last sentence is translated into a reference object

Rules for defining Reasoning Units

Once all elements have been marked in the transcript, identify reasoning units based on a change in the claim, premise, or both. For reference, follow the 'claim-premise decision chart.'

Claim	*Premise*	*Unit*
same	same	same
same	different	different
different	different	different
different	same	different

- If there is an implicit premise (P same) but a different claim (C diff), code as a new unit.

Example:

Elements of Reasoning	**Storyline**	**transcript**
P(diff)	[wooden board with holes]	L: Was ist denn mit einem Holzbrett mit Löchern?
P(same) C(diff)	[wooden board with holes] it floats	S1: Das schwimmt.
P(same) C(diff)	[wooden board with holes] it sinks	S2: Nee, das geht unter.

- A reasoning unit can be *big*, consisting of many speakers and/or speaking turns, or can be *small*, consisting of only one speaker (teacher or student) and/or one speaking turn.
- Speaking turns can be split. That is, if a change takes place within a speaking turn, that turn will be segmented into two separate units.

Example:

Elements of Reasoning	**Storyline**	**transcript**
P C	[large things] it’s weight (that make things float and sink)	S: sometimes big things, it’s weight,
P(diff) C(diff)	[small things] it’s mass or weight (that make things float and sink)	and sometimes small things, it’s mass or weight

- If there is a line that is marked as inaudible, but what the student/teacher said can be inferred from context, apply that statement to the appropriate segment of conversation. If the content of the statement cannot be inferred, that particular statement should be placed with the previous conversation segment. This also applies to other comments that are audible but not necessarily related to the ongoing dialogue.
- Uncoded segments (“junk”) will be left with the ongoing reasoning unit.
- Premises are always linked to claims. If there is a new premise and then a claim that relates to this premise several lines below, the two go together in reasoning unit (and the unit begins with the premise).
- If there is a change in premise without an accompanying claim then there is no change in the Reasoning Unit.

- If part of a claim starts in a teacher prompt but the premise is only defined in the following discourse, the teacher prompt should be made part of this reasoning unit to preserve the context of the statement.

  Example:

	L:	So. Ich habe hier die Würfel noch mal aufs Tonpapier gemacht und möchte die jetzt sortieren. Welches, welches, es geht ganz schnell. Welches ist der leichteste Würfel? (viele Kinder melden sich) Fabian?
[styrofoam cube] P1 It is the lightest C1	S:	Der Styropor.

Additional codes to "Reasoning in Science Classroom Discourse"

Conceptual sophistication

Each project site should give an additional code for the conceptual sophistication of the student statements depending on the domain and the already developed coding/level systems.

Optional additional codes

- Time code for proportion of time spent on reasoning / managerial time for each reasoning unit
- Overall argumentation structure