# Negotiated Representational Mediators: How Young Children Decide What to Include in Their Science Representations

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**ABSTRACT:** In this paper, we synthesize two bodies of work related to students' representational activities: the notions of meta-representational competence and representation as a form of practice. We report on video analyses of kindergarten and first-grade students as they create representations of pollination in a science classroom, as well as summarize results from interviews regarding the design choices that they made. Analysis of the semistructured pre- and postinterviews reveals that students attend to the content domain, local activity, and their personal preferences when evaluating representations. Analysis of video case studies that followed the students as they created their representations further reveals several key mediators of the students' representational activities, including other students, task constraints, the teacher, and local norms for what constituted a "good representation." In addition, the data show that these norms shifted over time as new content was covered in the class, and were appropriated in interaction with other students. Finally, both sets of analyses reveal that students often face competing constraints when creating their representations, and resolve these constraints through a complex set of negotiations. © 2006 Wiley Periodicals, Inc. *Sci Ed* **91:**1–35, 2007

## INTRODUCTION

External representations have consistently played an important role in educational theory and research, particularly with respect to math and science (Bell & Linn, 2000; Lynch, 1988; Suthers, 2005; White, 1993). It has been demonstrated that representational choices can impact problem solving (Kotovsky, Hayes, & Simon, 1985; Larkin & Simon, 1987), communicating ideas (Goodwin, 1994; Hall, 1996; Roth & McGinn, 1998), and learning new concepts (Greeno, 1987; Kaput, 1991; White, 1993). The work reported in this paper aims

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to build on and synthesize two specific areas of the literature addressing representations[1] in education. First, this paper aims to elaborate our understanding of meta-representational competence (MRC)—the ideas and resources that enable and constrain students as they create, modify, select, critique, learn, and understand representations (diSessa, 2004; diSessa, Hammer, Sherin, & Kolpakowski, 1991). Second, this paper aims to build on practice-based theories of representational activity that aim to understand representation use and creation as situated in culturally meaningful activity (Goodwin, 1994; Hall, 1996; Lehrer & Pritchard, 2002; Roth & McGinn, 1998).

In this paper, we examine a kindergarten and first-grade science classroom engaged in inventing representations (e.g., drawings and sculptures) of pollination and coordinate analyses sensitive to what individuals think about their own and others' representations with analyses sensitive to the contingencies and structures of the social interactions through which students are actually creating their scientific representations. Pollination, a regular part of the curriculum in the classroom we observed, was selected as the content topic for this study because it is an important complex system that is an integral part of the life cycle of plants and some insects and animals. By complex system, we mean a group of interdependent elements forming a complex whole where the global phenomena emerge from the local interactions of these elements (Wilenksy & Stroup, 1999). Understanding the life cycle of plants and animals within an environment, as well as how they are interrelated, is a topic that is listed as important in the national standards for elementary school science (National Research Council, 1996). However, learning complex systems such as pollination often proves difficult because each element is learned in isolation. Because of this, students often end up with only a superficial understanding of the various parts of the system with little understanding of the causal relationships between them (Hmelo-Silver, 2004; Hmelo-Silver, Holton, & Kolodner, 2000; Hmelo-Silver & Pfeffer, 2004; Wilensky & Resnick, 1999). Learning a complex system in terms of these superficial structures has been shown to make it harder for students to ultimately learn deep features and causal relations that are the more important aspects of the system (Hmelo-Silver et al., 2000). While we did not measure specific learning outcomes in this study, the content covered by the teacher attempted to address this issue by progressing from the specific details of the flowers and pollinators to a more robust understanding of how these features were interrelated. As we will show in the discussion of the interview results later, this shift from specific details to relationships between details was a common theme in students' representational choices.

In our analysis of the students' creation and discussion of representations of pollination, we make use of both the theoretical perspectives of MRC and representations-as-practice. Each of these perspectives leads to an analytic focus on different aspects of the phenomenon being observed, and each is more or less useful for different purposes. One of our central aims is to examine how classrooms are organized in ways that lead individuals to appropriate certain habits of mind in relation to the production and evaluation of scientific representations. As our analyses will show, investigating the origins of an individual's competencies at creating and critiquing scientific representations led us to closely analyze the social contexts in which these skills are first negotiated and practiced. This, in turn, led us to develop a new analytic framework that we have termed Negotiated Representational Mediators (NeRMs). This framework highlights that any given representational act—whether it is the

[1] A number of authors have chosen to use the term "inscriptions" in order to clarify their interest in materially inscribed external representations as opposed to internal mental representations. However, while the work reported in this paper also focuses on external inscriptions rather than on internal representations, there is no a priori reason that our theoretical claims will not also apply to other representational forms such as speech or gesture that are not typically included under the label inscriptions. Therefore, we will use the term "representation" throughout this paper.

construction, presentation, or use of a representation—is *mediated* by multiple factors, and that the coordination and prioritization of these mediators is *negotiated* in social interaction prior to being appropriated by individual students as a stable competence. In addition, the presence of multiple mediators frequently leads to individuals having to further negotiate between them when resolving a particular representational challenge.

We first briefly address the question of whether or not young children can be expected to create representations. Then, we report on the existing studies of MRC and then summarize the research from an alternate perspective that examines the use of representations as a form of social practice. Next, we present the findings of the present study beginning with a summary of the major trends observed in interviews with the children and ending with an interactional analysis of two video case studies. Finally, we will discuss the implications of the *NeRMs* framework for studies of students' representations and for classroom practice.

## Can Young Children Represent?

Well before entering kindergarten,[2] students are able to produce representations and understand their symbolic functioning. For example, students have been shown capable of recognizing familiar objects in pictures as early as 2 years old (DeLoache & Burns, 1994), and to produce effective graphic symbols for communicating with an interlocutor when solving a problem by the age of 4 years (Callaghan, 1999).

Children from the ages of 4–7 years (roughly the time that they would typically be enrolled in kindergarten or first grade) show a tendency toward intellectual realism based on their understanding of the object that they are representing—children at this age generally think there are few critical features that must be included (Cox, 1992; Piaget & Inhelder, 1966/1978). However, kindergarten and first-grade students have also been shown to be less adept at including all of the relevant details in a given representation than older students (e.g., third or fifth graders) (Tversky, Kugelmass, & Winter, 1991). There is reason to believe that even as early as 4 years old, students are responsive to critical feedback regarding their representations, which may lead to different representational choices (such as including more details) and ultimately to students being socialized into representing in a potentially domain specific way (Callaghan, 1999). Therefore, we assumed that the kindergarten and first-grade students in our study had some facility with creating and using representations. Our analyses aimed to unpack students' representational practices and capabilities and to further understand the various factors that influence students' creation and discussion of representations.

## Meta-Representational Competence

If we want students to become more than just consumers of science and preexisting scientific representations, then students need to be given opportunities to invent, modify, and discuss representations (diSessa & Sherin, 2000; Greeno & Hall, 1997). It is within the process of expressing and debugging one's own ideas that we begin to see the full power of representations and the ways that representations support students as they solve problems, communicate, and learn. The term "meta" in MRC refers to the aspects of student thought and activity that are "beyond" the specifics of any particular representation. MRC refers instead to the aspects of student thought involved in creating and analyzing representations in general. For example, a student attempting to create a bee out of clay that would not be too lopsided and fall down would leverage her representational competence with clay, as

[2] The average age of students entering kindergarten in the classroom we observed was 5 years.

opposed to her MRC. However, the student's concern with depicting the bee at an appropriate level of detail to convey that it is in fact a bee and is in the process of pollinating a flower would be an example of MRC because the student is thinking about what makes a good representation in general (i.e., it fits with an audience's expectations) and how that general feature applies to this context (i.e., the details of the bee are necessary to show pollination).

Researchers have argued that students work from a rich base of MRCs as they create representations, and that these competencies are generalizable, applying to a wide variety of activities ranging from drawing to computer programming (diSessa, 2004; diSessa & Sherin, 2000; Enyedy, 2005). For example, in inventing a new representation of a novel concept or situation, students pull from their vast and varied experience with drawing; making use of their ideas about lines as they create graphs (diSessa et al., 1991) and their experience with shading and perspective as they create maps (Azevedo, 2000; Enyedy, 2005). More importantly, developing these skills has the potential to enable students to understand how and why conventional representations of science are effective.

diSessa and Sherin (2000) specified a preliminary taxonomy of different aspects of MRC. This taxonomy has four categories: Invention, Critique, Functioning, and Learning. *Invention* refers to constructive resources, which are the skills and knowledge that students have, enabling them to invent or design new representations. *Critique* refers to the critical knowledge that students have about how to assess and compare the quality of different representations. *Functioning* refers to the degree to which students understand the role of representations and what they are used for. *Learning* refers to students' ability to learn and use new or unfamiliar representations. This includes the resources and techniques that students use when they attempt to understand new representations and use them to solve problems. While these different categories appear to suggest different contexts in which the various representational and meta-representational competencies are relevant, we have found it productive to more thoroughly unpack the notion of context, and the way in which different competencies come to be used in various contexts by examining representational acts as a form of practice.

## Representation as a Form of Practice

It has also been argued that in order to understand an individual student's representational performance, whether an act of creation, evaluation, or otherwise, it is necessary to understand the practice in which the performance was developed (Hall, 1996; Roth & McGinn, 1998). After all, "[representations] are usually crafted to be relevant to particular purposes" (Roth & McGinn, 1998, p. 45) and representations are effective because of the way in which they serve this particular purpose under specific conditions (Latour, 1987, 1988; Roth & McGinn, 1998). Students' ability to effectively employ a representation is, therefore, linked to their ability to take advantage of its affordances for a particular context. In fact, what appear to be individual difficulties with a particular representation can often be traced to a student's lack of understanding of the context in which it is being used (Roth, 1997; Roth & McGinn, 1998). Therefore, while individual students do in fact have competences—both representational and meta-representational—which are relevant to understanding their ability to complete a given task, in order to truly understand a given representational performance by a student, it is also necessary to examine the way in which the individual student is aligned with the local context and the representational practices that are seen as legitimate within that context.

To examine the way in which the use of representations is situated in a particular practice, many theorists have turned to examine the work of professional scientists. Studies of professional practice have shown the benefit of examining the practices that surround

representation in order to understand the way in which their creation and use is situated in ongoing activity. For example, Ochs, Jacoby, and Gonzales (1994), in their studies of physics laboratories, demonstrated the way in which scientists made their representations part of their ongoing discussions and attempts at meaning making by using them interactively with their peers, modifying them and gesturing over them as they were discussed. Their analysis highlighted the fact that understanding the representations and their impact upon the physicists work *required* an understanding of the practice in which they were made to be useful, and the fact that representations were rarely used as static finished objects.

More generally, Goodwin (1994) identified the development of *professional vision*—a set of practices, unique to a profession as a whole—for identifying and highlighting relevant information and details, as well as procedures for producing and articulating material representations. Important to Goodwin's analysis is the way in which individuals are socialized into this form of professional vision. We believe that students in a classroom develop something akin to professional vision (Stevens & Hall, 1998), and we further elaborate the way in which the norms surrounding representations carry across "professions" as well as across contexts within a given profession.

To understand classroom contexts, and the influence that they have upon learning, Cobb, Stephan, McClain, and Gravemeijer (2001) propose analyzing the collective learning of the entire classroom. Individual learning is viewed as a reflexive component of the collective learning. To describe mathematical learning, they identify three relevant aspects of the collective or social aspect of a mathematics classroom: classroom social norms, sociomathematical norms, and classroom mathematical practices. Classroom *social norms* for participation refer to taken-as-shared ways of interacting within the classroom, such as the need to justify solutions. *Sociomathematical norms* refer to those norms that are specific to mathematical work, such as what counts as a valid mathematical solution. Finally, classroom *mathematical practices* refer specific ways in which tools and procedures are used to achieve mathematical goals. According to Cobb et al. (2001), each individual has a psychological correlate of the norms and practices established at the collective or classroom level. As they participate within these classroom practices, individual students are continually renegotiating and developing the practices and norms as well as appropriating them. Our focus will, therefore, be on those socioscientific norms that are relevant to representational practices.

Several studies that attempt to apply the notion of representational practice to classroom settings have also identified the importance of examining practices as they change and carry across contexts for understanding the development of conceptual understanding in classrooms. For example, Lehrer, Strom, and Confrey (2002) argued that mathematical learning within a classroom arose as a result of the students' use and creation of a series of representations that resonated with various aspects of the mathematics being taught. Several norms for how representations were used or interpreted, such as the use of a line in graphing to represent a generalization, were used across episodes as well as being spontaneously used across multiple contexts. Each use helped refine the students' notion of how and when to apply this representational norm and the concept underlying it. Other studies have also found that representations that were spontaneously created across a series of different practices and shared between students lead to important conceptual development (cf. Enyedy, 2003, 2005; Hall & Rubin, 1998; Roth, 1996).

## NeRMs as an Analytic Frame

We would like to build off both the MRC and the practice-based perspective in our present analysis. The notion of MRC is a valuable analytic tool to understand the process

through which individuals invent new representational forms and learn how to effectively use conventional representations (Enyedy, 2005; diSessa, 2004; diSessa et al., 1991). In addition, by definition, MRC theory aims to define and describe those aspects of students' representational competences that are general and generative across multiple settings. On the other hand, the strength of the practice-based approach lies in its close attention to the details of how each new situation and its contingencies are made to be similar through various practices, and to how representation practices are situated in material, social, and historical contexts.

Our interest in this paper is developmental. We seek to understand the process by which young students converge on a similar set of beliefs and skills about what makes a good representation in science class. Although it seems appropriate to think of these types of skills and competencies as belonging to individuals, when we attend to the development of these competencies or even how these competencies are displayed, the social context plays a large role. Consider a child who is drawing a picture of pollination to convey the idea that a bee approaches the flower in search of nectar for food but unintentionally carries pollen that has rubbed off on it to another flower. In drawing the picture, we can see that several of the categories that diSessa and Sherin (2000) suggest come into play; we can imagine that the student is thinking about what is important to include and how to show it using her experience with drawing (invention), what she has left out (critique), where others might get confused, or what they might be able to do that they could not do without the picture (function).

However, the list of what our hypothetical student thinks is important to include, and even the fact that she is aware of a list of things that will be important to include, was developed over many interactions with her teacher and peers. Likewise, her ability to pick out what aspects of her representations are lacking have been picked up through interactions—including those where similar critiques were leveled against her own previous representations. Her ability to anticipate the difficulties of others and the coupling of form and function may also come from her own experiences of having to explain to others what she thought was obvious. It is through this history of interactions with others, over and through representations, that students come to be able to display the competencies by themselves.

Take, for example, diSessa et al.'s (2004) original description of MRC where the students were asked to represent the motion of a car that was speeding through the desert, slowed down and stopped, and then sped off. Many of the students' earliest drawings were cartoon-like pictures of cars, cacti, and bright suns. It took the teacher several days to focus the students to exclusively represent the motion of the car abstracted from the objects and referents of the story. If one attends only to MRC in this example, then either students developed a new competency for judging the quality of representations (something akin to parsimony) or this competency already existed and all that was changed is that they learned how to apply it to this context (they learned that for this classroom parsimony meant abstracting motion from the context and only representing the former). However, the notion of MRC, because it describes the competency and not the mechanisms for learning and development, provides little direction for understanding how and why this change occurred or how to replicate it in another classroom.

Given our goals to investigate the details of the ways in which MRC develops in the context of negotiations with the teacher, with their peers, and sometimes with themselves, we felt it necessary to reconceptualize MRC in a way that recognizes that what is included in a representation and what makes a good representation are socially mediated, open to change, and negotiated within ongoing activity. We use the term "negotiated representational mediators" to describe the factors influencing both the process of making (or critiquing) a representation and the process by which the practice develops over time.

Unpacking this term in reverse order, representational *mediators* refer to those elements that stand between the student and a representational performance or choice. Mediators can include (but are not limited to) an individual's goals, the larger motives shared by a group that gives rise to an individual's goals; an individual's understanding of the referent; an individual's personal preferences, the physical environment in which an individual or a group is creating their representation; the tools that are available; the other people present (or imagined); the social structures that facilitate coordination between people; and the local norms for the specific classroom or context (in this case, science class) that dictate the "appropriate" way in which students should engage with other people and artifacts.

It is important to note that these mediators include both representational and MRCs (among other factors), and that at any given moment multiple mediators may apply to a student's activities, and may even conflict. Our choice to focus on multiple mediators was made in part to overcome the fact that it was often difficult for us to make clean distinctions between representational and meta-representational competences, particularly when examining students who are in the early stages of learning how to represent a concept scientifically. In our analyses, both play an important role, particularly as they relate to each other, and therefore should be unpacked.

We have, therefore, also found it productive in our own analyses to focus on the types of negotiations that exist around student-mediated activities. The modifying term *negotiated* highlights our focus on the social interactions that we believe to be the engine of change and development. Rather than labeling those factors that might be identified as the individual's competence (meta- or otherwise) or reifying the specific practices that dictate the choices made (as is common in the representational practice approach), we examine the negotiation process in which the individual students engage as part of their ongoing participation within (and construction of) their local practice. By examining the way in which students and teachers *negotiate* these mediators, we are able to describe a rich set of resources and contextual factors that lead to representational inventions and accomplishments, the ways that conflicts or contradictions may arise between mediators, the process through which these conflicts are resolved to understand the students' representational practices, and the consequences of these resolutions for individuals and for the future, joint activity of the classroom.

The NeRMs framework is ultimately complementary with the MRC perspective. We foreground the importance of negotiation in practice and focusing on negotiation instead of competency to help identify a number of mediators that shape the way in which representational acts are locally performed and the social processes that contribute to individuals becoming competent at creating, interpreting, and using scientific representations. Our notion of NeRMs adds an important interactional component to studies of MRC not present in many of the earlier studies (cf. Enyedy, 2005). This perspective also widens the analytic lens to include more than individual students' understandings and skill, to begin to address the overlap between the way in which students choose to represent their understanding, and the norms of the community in which they are participating (Roth & McGinn, 1998). Finally, our developmental approach begins to unpack the process through which students appropriate the different mediators of students' representational activities, including their MRC, over time.

The NeRMs approach is also compatible with the notion of representation as a form of practice in that it identifies the ways in which practices happen in local contexts, and what individuals make of and appropriate from their interactions with others—what Cobb et al. (2001) referred to as psychological correlates. As such, the NeRMs framework attempts to bridge the gap between MRC and the practice notion of representations by analyzing the way that socialization into a community that uses representations in a particular way influences, and at the same time is influenced by, individual acts of creativity.

## METHODS

### Participants

This study was conducted within a kindergarten and first-grade mixed-age (5–7 years old) classroom at a progressive elementary school in southern California. The classroom had one lead teacher, Mrs. English,[3] who had been teaching for 28 years, 5 of them at the present school. There were also one support teacher and one teaching assistant available during most of the day. Finally, there were two researchers present who were responsible for videotaping the case-study groups, but who at times interacted with the children.[4] While all classrooms are unique, the classroom we observed had two features that are particularly relevant to this study. First, the teacher followed the Reggio Emilia approach to early childhood education that stresses the role of creating and examining representations as an ongoing part of their educational activities. This means that the majority of the science activities that the students engaged in involved their creating and discussing representations even before our study began. Therefore, it is likely that the students were both familiar with, and comfortable with, these kinds of activities. In addition, the classroom environment was one in which students were given a great deal of freedom to move around and discuss their ideas as they engaged in their work. Therefore, the kinds of interactions that we describe below in which students were interacting while creating individual representations were common, and often encouraged in this classroom.

The class consisted of 22 students, 21 of whom consented to participate in this study: 9 kindergarten students (5 boys and 4 girls) and 12 first-grade students (6 boys and 6 girls). This included 10 Caucasian students, 6 Latino students, 1 African American student, 1 Asian student, and 3 students reporting a mixed ethnicity. Prior to the study, the teacher had organized the students into four heterogeneous, mixed-grade, mixed-ability groups. The students had been working in these groups for several months at the beginning of the study. Two groups were selected by the teacher to be followed as video case-study groups by a process of elimination. Of the four groups, one group was eliminated because it contained the student whose parents opted not to sign the consent form. The other group was eliminated from consideration because it contained several children who the teacher thought would be too distracted by the video camera and filming.

### Procedures

This was primarily a participant–observer study. All science activities were videotaped using two cameras for the duration of the study. Each researcher followed the same case-study group for all three activities to ensure consistent interaction with the students and consistent videotaping technique. Students participated in three sequences of activities. For each activity, the students were asked to represent pollination, using different materials such as clay, "found" materials (i.e., scrap paper, plastic containers, and cardboard tubes), or paint. We refer to these as the pre-, introduction, and postactivity sequences. The pre-activity sequence included four activities: creating a sculpture of pollination, representing pollination using plastic manipulatives, drawing storyboards of pollination, and making copies of Georgia O'Keefe paintings. The different groups participated in this sequence in different orders. However, all preinterviews were conducted after the students in a group had completed their sculpture, and used the clay sculpture as the focus of the interview (see below for a more detailed description of the interviews).

[3] All names are pseudonyms.

[4] The first author, who also conducted all of the interviews, was a regular participant within the classroom for 7 months prior to the beginning of this study and was therefore very familiar to the students.

During the introduction sequence, the teacher introduced the students to the concept that it is important for an observer to understand a student's representations without explanation being necessary. Students were also introduced to the idea that pollinators are matched, or well suited for specific flowers. For example, some flowers are very "deep" and therefore might require a pollinator such as a hummingbird, which has a long beak to reach the nectar that smaller pollinators such as bees would not be able to match. The introduction activity sequence included an activity in which the students created a pair of flowers using "found" materials, an activity in which the students created the appropriate pollinator for someone else's flowers also using found materials, an activity in which the students created sculptures of pollination from wooden blocks, as a group, and an activity in which the students drew pollination, using the KidPix program on the computer. The postactivity sequence included only one activity during which students were asked to create pencil drawings of pollination with the requirement that the drawing be self-explanatory. Postactivity interviews were then conducted in the presence of the self-contained drawings.

The practical work of video analysis roughly follows the methods laid out by Hall (2001) and the methods of grounded theory (Glaser & Strauss, 1967). The videotapes themselves were first logged to outline the major events. Tapes determined to be of analytic interest were then transcribed. In addition, segments chosen for closer analysis were retranscribed to include the pauses, overlaps, intonations, and gestures that can often change the way an utterance is interpreted. The analysis progressed iteratively, sometimes working with the videos directly to better see the visual flow of the interaction, sometimes reading just the transcript to look for repeated words or patterns in phrasing.

Candidate episodes for analysis that either illuminated the interview codes, or added to our working theoretical framework for how the students created their representations in interaction, were selected. The ideas examined within these episodes were then tested for representativeness by comparing them with the rest of the data corpus; any ideas that were not present in at least three episodes were then not considered representative. Disconfirming evidence was also used to rule out working ideas; if students appeared to violate what we had previously thought was a norm without remark, we reconsidered its status as a norm.

The pre- and postinterviews were conducted within 2–3 days of the activities to limit the extent to which the students might have forgotten their representational choices. The first author, who was well known to the students, conducted all of the interviews at a small table in the hallway just outside of the classroom during regular classroom lessons. In addition, the representation that was the focus of the activity was present for the student and the interviewer to refer to. The interviews were semistructured; the interviewer followed a predetermined list of questions but took the opportunity to ask additional questions to either follow points of relevance to students' representational choices or attempt to gain clarification. The case-study students were asked a larger set of questions than the non–case-study students. The questions that were asked of all students were designed to elicit their general ideas about their own representation, including what they felt were the important aspects to include. The questions that were asked only of the case-study students were designed to further probe the students' values as they critiqued a representation (both their own and a comparison representation used for all of the interviews) and discussed the role of their representation in learning and explaining pollination. The comparison representation was created before each round of interviews to intentionally violate some of the norms that appeared present during the activity and therefore potentially elicit critiques. For example, all of the students in the postactivity created a drawing that included only two flowers, and so the comparison representation had an additional flower, which several of the students remarked was distracting. All interviews were limited to 15 minutes so that the students

would not be forced to miss class or maintain attention for too long. The interviews were all videotaped and then transcribed for analysis.

***Coding of Interview Data.*** The interview data were analyzed to catalog the students' ideas about their representations. We reviewed the data in several passes to induce codes, making notes about possible codes and families of codes. A small sample of the transcripts was first randomly selected to generate an initial set of codes based upon the types of answers provided by students. After several codes were generated, an attempt was made to apply these to other transcripts within the data set. At that time any modifications, such as generalizing codes, collapsing codes, or adding additional codes, were made. An initial set of codes and examples was presented to our research group for suggestions and critiques, leading to additional revisions. During each pass, the goal of revising the codes was to create a set of codes that, as a whole, were general enough to cover the majority of the utterances, while also being specific enough to make for meaningful comparisons between them. Once the code categories were determined, they were applied to all of the interviews by one of the researchers. A second researcher coded six of the transcripts (14.3%) to help assure reliability. Interrater reliability was 80.9% overall.

Three families of codes were induced from the data to label the students' comments as referring to the individual, the content domain, and the activity. Generally speaking, *individual codes* apply to statements in which the students discussed a personal preference, thought, or other idea that may be construed as originating with them. *Content domain codes* refer to statements by the students that are about the scientific content they were studying including flowers, pollinators, or pollination as a whole. In addition, content domain codes included socioscientific norms, such as norms for what makes for a good scientific representation in this classroom. Finally, *activity codes* apply to statements in which the students mentioned an aspect of the activity or activity system—the "junction of cultural artifacts, beliefs, values, and normative routines" (Gutierrez, 2002, p. 313)—in which they were engaged. References to the activity system include mention of material constraints, a direction from the teacher, or the influence of other students.

Because of the inductive nature of our coding scheme, these three families of codes do not cleanly map onto diSessa and Sherin's (2000) taxonomy of MRC. However, in reporting our results, we will attempt to draw attention to where there are connections between the two coding schemes. In addition, our codes are not mutually exclusive, and allowed each utterance to be coded simultaneously in more than one family. A summary of the frequency of the codes and subcodes, as well as brief descriptions for each code, can be found in Table1.[5] Note that only 5 of 762 items were coded as "other," implying that they could not be fit into any of the three families. Therefore, these will not be discussed further here.

## RESULTS

A series of three paired $t$ tests[6] was conducted to determine whether there was a significant shift in the percentage of student utterances that were coded using each of the three families of codes—individual, content domain, and activity based. To decrease the likelihood of type 1 error, a Bonferroni adjustment was calculated, resulting in the use of a critical value of .0167 for the individual $t$ tests so that a familywise error of .05 was calculated for

[5] Codes for specific types of answers such as "yes," "no," and "I don't know" were also generated. However, as these codes were not used for the present analysis, they will not be presented here.

[6] In addition, all data were plotted and examined to determine that one or two outliers did not cause the observed changes; histograms of student response percentages were roughly normal in their shape.

**TABLE 1 Interview Code Summaries**

| Code | Description | Pre | | | Post | | |
|---|---|---|---|---|---|---|---|
| | | Sum | Mean | % (of family) | Sum | Mean | % (of family) |
| **Activity** | **References to the activity system** | **119** | | **33.0** | **120** | | **30.2** |
| Audience | Some acknowledgment of the audience being a key motivating factor in the representation. This often takes the form of pointing out how something "looks" a certain way. | | | | | | |
| | Example: "It wouldn't look very good because no one would understand." | 19 | 0.9 | 16.0 | 53 | 2.5 | 44.2 |
| Community nice | Some students felt it was important to accept people as they were. For example, it is unfair to expect them to understand your representation. | | | | | | |
| | Example: "If they knew all the parts, and the kid didn't know the parts, it wouldn't be fair to them." | 3 | 0.1 | 2.5 | 3 | 0.1 | 2.5 |
| Functional affordance | The representation has some functional affordance such as the fact that the representations can be used as a visual reference when explaining pollination to someone. | | | | | | |
| | Examples: "Like if they didn't understand me, the picture, I can show them." and "Every sculpture about pollination is good to learn." | 14 | 0.7 | 11.8 | 17 | 0.8 | 14.2 |
| Group objective | The student expresses alignment with the objective of the class or teacher. | | | | | | |
| | Example: "Umm, because Ms. English said to, umm, umm, to make a sculpture, a flower to um, because she wants to see pollination, but umm, but not real pollination" | 21 | 1.0 | 17.6 | 20 | 1.0 | 16.7 |

*Continued*

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**TABLE 1 (*Continued*)**

| Code | Description | Pre | | | Post | | |
|---|---|---|---|---|---|---|---|
| | | Sum | Mean | % (of family) | Sum | Mean | % (of family) |
| Material constraints | Some aspect of the materials makes it difficult or unappealing to make certain representational choices. | | | | | | |
| | Example: "I didn't know how to make it like, be in the air like right here, so I made it on the flower with its tongue sticking out trying to get the pollen." "[the butterfly is] pretty hard to make it on a thing, and pretty hard to make it up here. So I made it like this." | 43 | 2.0 | 36.1 | 9 | 0.4 | 7.5 |
| Activity other | Other utterances related to Activity. | 19 | 0.9 | 16.0 | 18 | 0.9 | 15.0 |
| **Content domain** | **References to science, pollination, or subelements of pollination such as o wers, pollinators, and plants** | **147** | | **40.7** | **205** | | **51.5** |
| Global reference to content | The student refers to their representation in an aggregate manner (pollination) as opposed to specific details. | | | | | | |
| | Example: "I made a clay model of, of an insect pollinating" | 10 | 0.5 | 6.8 | 11 | 0.5 | 5.4 |
| Content details | There is a detail or fact related to flowers, plants, bees, or pollination that is referenced as important. This includes lists of important aspects as well as fidelity to the referent. | | | | | | |
| | Example: "They're missing like anth- the stamens and anthers, pistols, sticky stigma." | 95 | 4.5 | 64.6 | 76 | 3.6 | 37.1 |

*Continued*

**TABLE 1 (*Continued*)**

| Code | Description | Pre | | | Post | | |
|---|---|---|---|---|---|---|---|
| | | Sum | Mean | % (of family) | Sum | Mean | % (of family) |
| Content relationships | Some relationships either conceptual or spatial are remarked as important. Example: "the hummingbird [in the student's drawing] was going, was first on the bottom of it, and it's like, went up. And then it got the pollen. And it, or trying to get the nectar, but it got the pollen instead." | 35 | 1.7 | 23.8 | 100 | 4.8 | 48.8 |
| Content relationships and details | The student provided both a list of details as well as at least one relationship of importance in a lengthy explanation. Example: "Because on top of the thing that holds the sticky stigma, then they will sing on it, that, that's something that I don't really know what it is. That it's like a stigma. Sort of shaped like a, like this. [. . .] It, if any pollen gets on it, it, the hole will go down and it will, and it will make seeds." | 5 | 0.2 | 3.4 | 6 | 0.3 | 2.9 |
| Content distraction | Some extra details, even if accurate, are distracting, and therefore not desired. Example: "I would take away the grass [. . .] Because they might think that it's something about pollination and they might think that that's like something that needs to be for" | 0 | 0.0 | 0.0 | 11 | 0.5 | 5.4 |
| Content other | Other utterances related to the Content domain (pollination, or science in general) | 2 | 0.1 | 1.4 | 1 | 0.0 | 0.5 |
| **Individual** | **References that seem to be speci c to, and related to, the individual student** | **94** | | **26.0** | **72** | | **18.1** |

*Continued*

**TABLE 1 (*Continued*)**

| Code | Description | Pre | | | Post | | |
|---|---|---|---|---|---|---|---|
| | | Sum | Mean | % (of family) | Sum | Mean | % (of family) |
| Accomplishment | The representation is valued because it was in some way an accomplishment for the student. For example, if they worked hard, or overcame some difficulty. | | | | | | |
| | Example: "[I like this sculpture] Because it's, it's mine. I made the sculpture, and it's...I made it." | 14 | 0.7 | 14.9 | 17 | 0.8 | 23.6 |
| Attractive | The student thinks that some aspect of a representation is good, pretty, attractive, etc. Or, is not, and is considered a bad representation for that reason. | | | | | | |
| | Example: "color is good because it's, it's, it looks more bright to you and it looks pretty" | 17 | 0.8 | 18.1 | 5 | 0.2 | 6.9 |
| In the head | The student's answer is a reference to an idea they had, or something that was "in their head." | | | | | | |
| | Example: "Well, I just felt like making the hummingbird, because I feel like I was humming." | 11 | 0.5 | 11.7 | 3 | 0.1 | 4.2 |
| Personal preference | The student says that they like, or prefer some representational aspect with no additional justification. | | | | | | |
| | Example: "I like the color and I like the kind of flower" | 44 | 2.1 | 46.8 | 41 | 2.0 | 56.9 |
| Individual other | Other utterances related to the individual or their preferences. | 8 | 0.4 | 8.5 | 6 | 0.3 | 8.3 |
| Other | | 0 | | | 5 | | |
| **Total** | | **360** | | | **402** | | |

the set of 3. Our prediction, based upon the introduction of content within the classroom and consistent with our initial qualitative observation, was that there would be an increase in content domain codes, and that this would have a corresponding decrease in individual codes. This was predicted because the students had learned a number of additional facts about pollination that we expected them to represent instead of simply choosing their own personal preferences. While we did not expect the ongoing classroom activities to change the percentage of activity codes relative to the other code families, we did expect that the nature of the postactivity would make the audience more salient to students. This focus on their audience was therefore predicted to lead to a corresponding increase in frequency of the Audience code within the family of activity codes.

The percentage of total codes that were individual based decreased from 26 to 18.1. This decrease was significant: $t(20) = 2.40$, $p < .0167$, two-tailed. The percentage of total codes that were content based increased from 40.7 to 51.5. This increase was also significant: $t(20) = 3.80$, $p < .0167$, two-tailed. The percentage of total codes that were activity based decreased from 33.0 to 30.2. This decrease was not significant: $t(20) = -1.66$, $p > .0167$, two-tailed. The predicted increase in the students' attention to their audience is discussed below.

### Individual Codes

Individual codes were assigned to student utterances that identified aspects of themselves, their preferences, or their own thinking as important. These codes were not meant to identify individual cognitive processes, but rather to identify those times that the students positioned an idea as originating from their own thinking instead of being externally motivated. The most common individual code was Personal Preference (Personal Preference made up 46.8% of individual codes in the preinterviews, and 56.9% of individual codes in the postinterviews) and was used to identify student utterances that identified a simple preference using words such as "I drew a bee because I like bees."

An additional individual code of interest is the Accomplishment code, which refers to those times that students appeared to value a particular aspect of their own representation because they saw it as an accomplishment to have created it; for example, if the students said that they liked their representation because they had worked hard on it or if they were able to do something that they considered difficult. What is particularly interesting about the utterances that were coded in this way is that they tended to be expressed in a way that did not separate the representation from the process of creating it. In addition, as will be shown in Episode 2 of the video case studies presented below, there was in this classroom a local norm for participation that promoted working hard and carefully on a representation, and not simply rushing to complete it. Students' belief that a representation was good if it required a lot of work may, therefore, stem in part from the fact that their peers and the teacher evaluated them with respect to this criterion.

There was also an important shift in the frequency counts of individual codes. While students made fewer utterances coded as individual overall—a decrease from 26.0 to 18.1% of total codes—a number of students tended to use personal preferences to "anchor" their other ideas. As students began to make more of their representational choices on the basis of the relationships and other content details that they learned, they tended to link all of these to a personal preference idea when possible. For example, a student might have chosen to represent a hummingbird because it was his or her favorite pollinator and then represent a "deep" flower[7] because hummingbirds are well suited to gather nectar from deep flowers. However, the students were not simply using their individual preferences to mask the limits

[7] Students referred to flowers as deep or shallow, depending on the way the petals occluded access to the nectar.

of their content knowledge, but were systematically following the consequences of their preferences and choices. This illustrates the way in which students are often negotiating multiple competing mediators as they seek to make their representational choices, as well as the fact that the results of some of these negotiations could be seen in more distal choices (choosing a pollinator influenced not only the pollinator within the representation, but the flowers as well).

### Content Domain Codes

Content Domain codes were assigned to utterances that made reference to specific aspects of the content that the students were studying, such as facts about flowers, plants, and pollinators. Typically, students referenced the content domain to identify aspects of the system that had been represented, or were important to represent, such as details of the flower or pollinator. While diSessa (2004) identified an aspect of MRC in his studies that lead students to value fidelity between the representation and the object that is being represented, these codes demonstrate some of the ways in which fidelity was locally defined and negotiated within this particular classroom.

The majority of the content domain references were coded as Content Details: 64.6% of the preactivity sequence content domain codes and 37.1% in the postactivity sequence. The next largest category of codes, Content Relationships, was of those that referred to conceptual or spatial relationship between items in the representation as being particularly relevant. For example, several students explained that they chose a hummingbird as their pollinator within the postactivity sequence because that was the ideal pollinator for a deep flower (because it has a long beak that can reach the nectar). While detail and relationship codes are often found in students' descriptions of their own representations, they also frequently appeared in the critiques that students offered of the comparison representation. When used in this manner, student utterances coded as content codes were more similar to the MRC category diSessa and Sherin (2000) called "Critique." It appears, therefore, that our codes identify norms that are present across the different activities of creating and then critiquing a representation. For example, in the clay comparison sculpture created for the preinterviews, the flower depicted (a rose) did not include the parts of pollination that the students had been asked to represent. A number of students critiqued this violation of the norm with comments about the representation's author such as "[He] didn't make really all the parts. [. . . ] He forgot the ovules. He forgot the pistil."

Examining the shift in students' discussion of details and relationships over the course of the study provides an important entry point into examining the evolution of their understanding of the content and how it should be represented. Students made less detail references in the postactivity sequence (a drop from 64.6 to 37.1% of total content codes) while at the same time making more relationship references (an increase from 23.8 to 48.8% of total content codes). This was expected and might be explained by the fact that students continued to learn about the content throughout the course of the study, making it more likely that they would be aware of additional relationships after the postactivity sequences. Specifically, the teacher spent a considerable amount of time discussing the relationship between particular pollinators and the flowers that they are most likely to pollinate, and asked the students to include this in their representations. These relationships were identified by students both in describing their own representations and in critiquing the comparison representation during the interviews.

This trend toward valuing content relationships in the representations may elaborate one way in which the students' ideas about the content being discussed are influencing their representational activities. As their understanding becomes more connected and they

begin to understand the relationship between the parts of the pollination system, they want to include those relationships in their representation. On the other hand, as the teacher presented the relationships, she stressed the need to include them in the students' representations. The content highlighted by the teacher creates opportunities for the students to show alignment with and competence in the classroom objectives. Based on this, the trend toward including relationships also seems to point to the influence of the community and teacher in helping establish the students' goals for what should be included. However, in the current study it is not clear whether students place greater value upon representing relationships during the postactivity, or simply understand more relationships to represent.

### Activity Codes

The activity codes apply to student utterances that imply an acknowledgment of the activity system in which they were working. One particularly important aspect of the way in which activity systems have been theorized is the way in which individual activity is mediated by cultural artifacts and other community members (Engestrom, 1999). We used the expanded mediational triangle (Engestrom, 1987, 1990), which was designed to model activity systems, as a rough guide to what may be relevant in the local activity system. This includes references to the mediating role of artifacts, the division of labor, rules, and the local community in which the student is operating.

One particularly interesting aspect of the activity codes was the students' awareness of constraints of the materials that they were using. These references, which we did not expect to see in such high numbers, were most prevalent during the preactivity sequence. For example, when working with clay and wires, the students often acknowledged that the wire was better for making things that would stand up, or that the clay was heavy, and so representations that were top-heavy with clay would be prone to falling down. Most importantly, the students often acknowledged that they had to choose between the conflicting demands of the content and the material constraints in their activities. Occasionally, the students chose to ignore a requirement of the content in favor of the material constraints. In these cases, the students often included this choice in their description of why the representation did not quite match the requirements or their goals. The ways in which students encountered and resolved these challenges in interaction are further illustrated in the qualitative discussion below.

One instructional goal that the teacher adopted after the preactivity was to highlight for students the importance of designing their representations with an audience in mind. This seems to have been somewhat successful as there was a shift in the percentage of references to the audience from the pre- to postinterviews. Initially, students made a total of 19 (16.0% of total activity codes) references to the audience in their interviews. During the postinterview, however, they made 53 (44.2% of total activity codes) total references to the audience. An examination of the data shows that there was a corresponding drop in the references to the material constraints; from 43 (36.1% of total activity codes) to 9 (7.5% of total activity codes), although this drop may be explained by the change from clay to drawing with pencils and paper, materials that the students are more familiar with. While it is not possible to make any causal claims, given the nature of the experimental design, it appears that the types of materials that students are using in their representations, their facility with these materials, and the ideas that the teacher stressed as important are particularly salient mediators for students as they complete various representational activities, including interview discussions of their representations.

***Interview Summary.*** Analyzing the interview data allows us to make several observations. First, students' understanding of the content evolved over the course of the study,

and students' ideas about which content they needed to represent changed accordingly. Second, by the end of the study students appeared to place higher value upon content and less value upon their individual notions such as personal preference. However, even as students gave more content-based justifications and fewer individual justifications, they frequently anchored their representations in a personal preference, demonstrating the way in which competing influences may be negotiated in students' representational choices. Third, students' references to audience considerations increased over the course of the study in response to instruction and reenforcement from their peers. This is consistent with the intention and goals of the teacher.

***Video Analysis.*** We will now present an analysis of two episodes from the corpus of video data to further illustrate these three themes. We will also highlight some of the aspects of the interactions within the current classroom that we argue impacted students' representational activities. The episodes we have selected to present are representative of the kinds of interactions that we see throughout the data. This means that we saw each of the big ideas in several other episodes, during the course of our analysis, and did not find disconfirming evidence in other episodes. These episodes were chosen, however, for presentation because they contain several of these interactions in one brief excerpt making them easier to describe and elaborate.

The first episode took place during the preactivity sequence and focuses upon one student as he created a clay sculpture of pollination. The second episode took place during the postactivity sequence and focuses on one of the case-study groups as they created drawings of pollination. We will use these two episodes to illustrate the ways in which access to peers, peers' work products, and the teacher play important mediating roles in the way that children negotiate representational choices as they create representations. While some of the shifts in representational choices may be explained by the changes in what content was being covered in the class, these episodes also serve as more general examples of the way in which local interactions play a role in the ongoing negotiation of what makes for a legitimate representation.

## Episode 1: Getting the Bee in the Air

Episode 1 took place as part of the preactivity sequence. The three students (see Figure 1) who will be discussed in episode 1 are Chad (6 years, 6 months old), Charles (6 years, 10 months old), and Dan (6 years, 5 months old). Charles and Chad were both in the first case-study group while Dan was in one of the non–case-study groups. All three students were completing an activity from a previous day which they had not had time to complete. The present analysis will focus on Chad's activity as he created a clay sculpture of pollination. The episode took place approximately 28 minutes into the science activity.

The class had been discussing the parts of the plant for several months, but had begun discussing pollination only recently. Mrs. English required students to carefully represent all of the relevant features of the flowers for this activity, but allowed students more freedom in how they represented the pollinators, and the act of pollination. In the whole-class discussion that introduced the activity, Mrs. English elicited information from students as to what they would need to do in their sculptures to show pollination, highlighting the need for two flowers of the same type, and listed all of the parts of the plant that needed to be shown (e.g., the petals, pistil (female sex organ), and stamen (male sex organ)). However, Mrs. English also pointed out that aside from these important details, students should show pollination the way *they* wanted to (as opposed to a specific layout as specified by Mrs. English, other

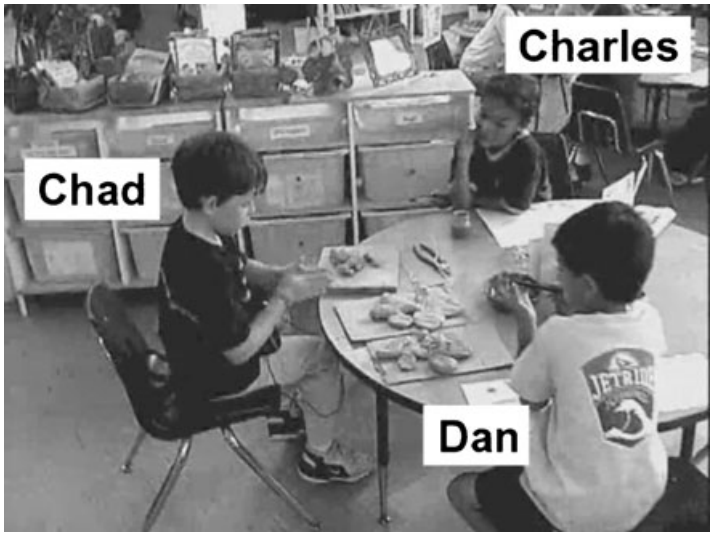


**Figure 1.** Students of Episode 1 helping Chad create his bee.

students, or any drawings of flowers on the board) so long as it would be clear to someone viewing the sculpture that it was in fact showing pollination. Reference materials such as posters of flowers, actual live flowers, and books about flowers or pollination were available throughout the classroom, and students were often encouraged to examine them in detail if they were unsure of the details that they needed to include in their representations. However, students were not all required to use the same reference, and so a variety of flowers (some of them made up) and pollinators was used.

The students worked individually on their sculptures, but were seated in their groups where they had ample opportunity to see each other's work, and to comment upon this work. The students had used clay several times[8] earlier in the year, and so were somewhat familiar with the medium. Each student was given a block of clay to being this activity, and had access to metal wire to be used with the clay; teachers were available to cut the wire to the desired length at students' request. For most of the students, this activity took one class session to complete. The students in Chad's group had all completed their sculpture in the previous science class, and Chad was completing his sculpture while the rest of his group began the next in the series of activities.

### Episode 1, Excerpt 1: How to Get a Bee in the Air

Excerpt 1 shows a brief interaction in which Chad sought assistance from his peers and the teacher in attempting to place a bee in the air above the flower for his sculpture of pollination. To discuss the NeRMs that appear to be most relevant in this interaction, we highlight the various resources that Chad and his peers made use of as they attempted to negotiate a solution to this problem. In particular, we will examine the way in which Chad negotiated a solution to the problem of how to represent the bee in his sculpture by first looking closely at how he framed the representational challenge he encountered and later

[8] Because we were not present for the entire school year, we do not have an accurate count of how often the students used clay. We do, however, know that its use was considerably less frequent than the use of other materials such as pencil-and-paper drawings.

relaxed the constraints under which he was operating, which in turn allowed him to select a particular solution. We also address the various mediators that were most relevant to this negotiation such as Chad's peers, the material environment, the teacher, and the norms of this classroom.

Excerpt 1

| | | |
|---|---|---|
| 1 | Chad: | Wh- Ok, so, how am I supposed to get the *bee* (points towards clay) in |
| 2 | | the *air?* (points to clay) (hh) (looks at Dan) |
| 3 | | (shifts gaze to Charles) Uh that's the hard part. |
| 4 | Charles: | Wait no, [just um just] |
| 5 | Dan: | [No, just put this] just stick this (points to, and then pick up a piece of |
| 6 | | wire) and then um put the bee on here |
| 7 | Charles: | No [um actually] |
| 8 | Chad: | [But then where would] I put that? |
| 9 | Charles: | Well you could um make the bee's tongue a little bit long and put like on |
| 10 | | one of the (ant-) (points at Chad's sculpture) or like [put it on one of the |
| 11 | | anthers |
| 12 | Chad: | [But it would be like h. It would be like right (points down) here and its |
| 13 | | tongue would go to there? (points at clay) |
| 14 | (Charles): | (Yeah. Chad Chad). |
| 15 | Chad: | Oh |
| 16 | | (5) |
| 17 | Charles: | Well, you don't have to because somebody's- |
| 18 | Chad: | (Gets up to go find Mrs. English) Ms. English? How am I supposed to |
| 19 | | make the bee. Getting the pollen. |
| 20 | Mrs. English: | Just, just think about how you want to. It has to be the way you want. |
| 21 | | (Chad sits back down and immediately begins manipulating the clay) |
| 22 | Charles: | Chad. Just uh stick it on like the anthers. That's a good idea isn't it? |
| 23 | | (2) |
| 24 | Chad: | I got an idea. |

## Social and Socioscienti c Norms as Mediators for De ning Representational Goals

There are a number of resources, both human and material, that mediated Chad's representational activity—including his peers, the material environment, the teacher, and the norms of this classroom. In identifying and solving his representational challenge, Chad revealed the way in which these different mediators are negotiated, ultimately leading to a specific representational production that was then seen as legitimate within this classroom.

Chad made it clear in line 1 that he wanted to finish his representation in such a way that the bee was in the air, but was not sure how. It is not entirely clear why Chad wants the bee in the air; whether because of a personal preference, a belief that is required by the teacher, because he believes it will make a better representation, or some alternative reason. However, our focus for this analysis is on the impact that his voicing this desire has upon his activities, and those of his peers. Several competing constraints appear to be present in this question: (1) Chad knew he needed to include a pollinator; (2) he wanted it to be a bee; (3) he knew that bees fly; and (4) he recognized that he did not know how to suspend a clay bee in the air above the flower he had created. In seeking help from his peers to resolve this tension, Chad adheres to a local social norm that holds that it is

acceptable to seek representational assistance from one's peers.[9] This social norm, however, has representational consequences in that his peers introduce several new potential solutions that can be evaluated. Furthermore, these different solutions recognize different constraints for the problem, which may be part of the reason that Chad ultimately solves the problem by not placing the bee in the air but instead giving it a long tongue to connect it to the flower as Charles had suggested.

When Chad rephrased his problem for Mrs. English, he did not ask her how to get the bee in the air. Rather, he asked her how he was supposed to make the bee (line 18). This seemingly simple paraphrase fundamentally shifted the nature of the question to be more general. There was no longer an implicit assumption that the bee should be in the air. However, Chad did mention "getting the pollen" (line 19) as part of his question. This highlights a socioscientific norm that is consistent throughout the data; the students acknowledged that certain details are necessary in a representation of pollination in order for it to adequately show pollination. Other details were considered optional. In this case, the "bee getting the pollen" was an important element that should be represented, whereas the way that the bee was depicted was optional.

This negotiation of what is important to represent and how it can be represented highlights the fact that the goals for what is contained in a representation and what makes a good representation are socially mediated, open to change, and negotiated within ongoing activity. For example, Chad's question revealed a negotiation between his desire to put the bee in the air, the norm of having the bee touching the pollen, and his difficulty with showing the bee in the air using clay.

At the end of the excerpt, Chad's question changed significantly—from getting the bee in the air to showing the bee getting the pollen. While this may not have been an intentional change on Chad's part, one result was that instead of eliciting a suggestion of how to get the bee in the air, when Mrs. English reminded him that he could make the pollinator any way he wants. This highlights one of the important subtleties of the Content Details code from the interviews; what constitutes a detail to be included is contextually defined, and changes over the course of the class. Put differently, the mediating role of the students' understanding of the content is renegotiated within each activity context.

The way Chad ultimately solved the problem of how to make the bee was by not putting it in the air. He instead chose a solution similar to Charles' proposal by placing a bee with a long tongue on the anther (see Figure 2). This design solution prioritized the content (i.e., placing the bee in relationship to the pollen) but did not acknowledge all of the constraints of Chad's original question (i.e., it did not have the bee in the air as it would in real life).

Throughout this process of representing pollination, Chad, his peers, and the teacher defined and then redefined the specific representational problem that Chad was attempting to solve. This case is an example of an explicit attempt by a student to negotiate the multiple representational mediators he was encountering. In this example, there seem to be several factors that mediate what Chad represents and how (1) his desire to put the bee in the air, similar to how it would appear in nature (i.e., a socioscientific norm of factual accuracy, typically seen in the Details code), (2) the goal of having the bee touch the pollen (i.e., a socioscientific norm of factual accuracy typically seen in the Relationships code), (3) his inability to place it in the air, given his knowledge and ability with the materials being used (clay and wire), (4) his requests for assistance (i.e., a social norm supporting requests and offers of assistance), and (5) Mrs. English's reminder that Chad could represent the bee according to his preferences. Factors 1, 2, and 3 are in conflict

[9] Although one example does not make it a norm, we have numerous examples of seeking and offering assistance throughout the video record.

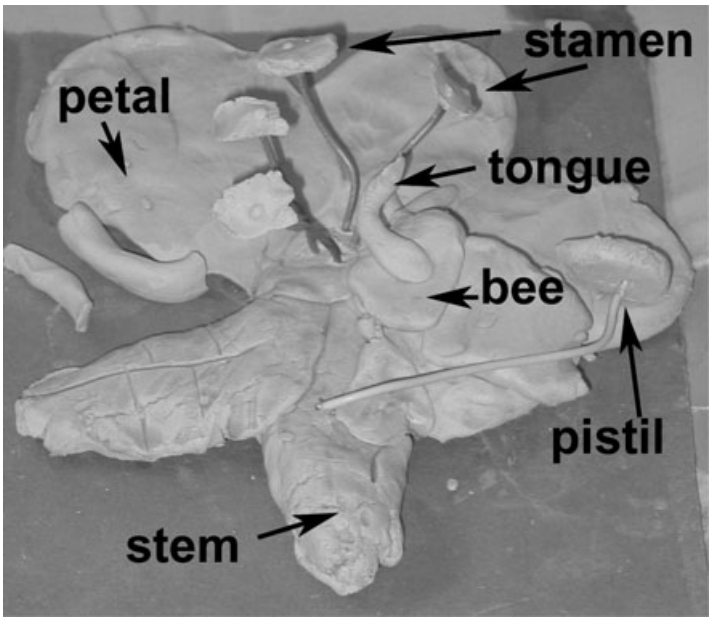


**Figure 2.** One of Chad's flowers, completed and labeled.

with each other, and Chad's final solution uses the fourth and fifth factors—that he could represent the bee however he wants to, coupled with his peer's suggestions—to come to an acceptable solution for the given task. Mrs. English's reminder therefore effectively served to change the nature of Chad's negotiation by relaxing a constraint that he had been applying to his own representation. Then, additional choices were made available to Chad by Charles' suggestion. This leads us to the second analytic point that we will discuss concerning this excerpt: how students negotiate and coordinate the resources that were available to them.

## Negotiating a Solution

While Chad's representational activity appears to be mediated by multiple factors, the most salient to our analysis is the group of people around him while he was in the process of constructing his representation. The availability of his peers as a resource to help him solve this problem was linked to the classroom culture, and the way it facilitated the potential for *open interactions* (Hutchins, 1993). In the current context, an open interaction means that the students had access to each other's representations as well as the opportunity to observe their peers as they created and negotiated their representations. Therefore, they could see and potentially comment upon the work of the other students, which they did rather frequently. This form of open interaction was itself a result of local social norms and the physical configuration. In this particular episode, the openness is partially enabled by the fact that two of Chad's classmates were sitting around a circular table with him, with easy visual access to his representation. He took advantage of this by posing his question without moving from his seat, and by gesturing over the representation to illustrate where the bee might be placed in the air above one of his two clay flowers.

Chad had a great deal of agency with respect to his participation in this activity and the advice he accepted from his peers. This can be seen in line 24 when he shut down further discussion with Charles by saying that he had "an idea." Charles then stopped

making suggestions. Agency is an important part of the way students may make use of open interactions. They choose which mediators are relevant to them, and when. While Chad was willing to request, and entertain proposals for how to complete his design, he did not imply that he would follow these proposals. Chad appeared to not only have been planning, or designing his representation interactively, but he also constantly evaluated the proposed plans as they were represented to him, determining whether they satisfied the constraints of the task as he saw them. From the perspective of theories of distributed cognition (e.g., Norman, 1991), Chad did not simply gain assistance; he altered his task to one of first making sense of his peer's suggestions, and then evaluating them. This can be seen most clearly when Chad challenged Dan's suggestion with a clarifying question, and ultimately did not use the approach suggested by Dan.

### Episode 1, Excerpt 2: Assessment of the Solution

The second excerpt in Episode 1 began approximately three and a half minutes after Excerpt 1 ended. The students had been working individually for that time, talking mainly about nonacademic topics. Chad completed his representation of the bee and then asked Mrs. English to look at the sculpture. Mrs. English asked several questions, helping to remind Chad of the details that needed to be included in the representation.

Excerpt 2

| | | |
|---|---|---|
| 1 | Chad: | (hh) Look at my bee (standing up, pointing) (hh) it's getting the pollen |
| 2 | | (2.0)(walking around the table towards Mrs. English) |
| 3 | | Ms. English? |
| 4 | Mrs. English: | Yes honey? |
| 5 | Chad: | (uhuh)(points as he returns to his seat) |
| 6 | Mrs. English: | Oh my goodness. |
| 7 | | (4.0)(walks over to look at Chad's sculpture) |
| | | Wow. Beautiful. What is this? |
| 8 | Chad: | That's the bee's tongue. |
| 9 | Mrs. English: | The bee- (hhh) ok. Now. I see a lot of stamens. Do they- what other part |
| 10 | | is there to the flower that's very important. |
| 11 | (?): | [Pistil |
| 12 | (?): | [Sticky Stigma |
| 13 | Mrs. English: | Stamens and the- |
| 14 | Chad: | Pistil |
| 15 | Mrs. English: | Pistil. Do we have pistils? |
| 16 | Chad: | No |
| 17 | Mrs. English: | If we don't have a pistil can we have pollination? |
| 18 | Chad: | No |
| 19 | Mrs. English: | No:. So you need to have the pistils too, right? So think about that. |
| 20 | | (Mrs. English then directs her attention at another student) |

### Representing Content Details as a Form of Social Practice

After Chad answered Mrs. English's question and identified the part of the representation in question as the bee's tongue (lines 8 and 9), Mrs. English laughed, treating the elongated bee tongue in a light way that reenforced the fact that the fidelity of details with the referent, which was so often important in other aspects of the representation, was not necessary with regard to the representation of the bee. In contrast, during the postactivity sequence,

pollinators were expected to be represented more realistically. This also served to validate Mrs. English's earlier statement (Excerpt 1) that Chad could represent the bee in any way he wants. In these ways, Mrs. English is an important mediator, embodying the classroom norms for Chad.

Immediately following her laugh about the bee's tongue, Mrs. English began to ask a series of questions about the parts of the flower (lines 9–19), leading Chad to ultimately acknowledge that the Pistil (the female sex organ of the flower) was also an important for pollination and therefore should be present in the representation. In this series of questions, Mrs. English was essentially mediating Chad's access to, and awareness of, his own knowledge of pollination and how it should be represented. While these questions take the familiar form of "known-answer" questions (Lemke, 1990; Mehan, 1979), Mrs. English was not simply telling Chad what needed to be added to his representation. She was identifying missing elements of the representation and helping Chad reason through the consequences of those missing elements. It is also important to note that (a) her questions came at the exact moment when Chad was trying to decide what changes, if any, were needed to complete his representation; (b) her questions were framed in a way that modeled the important link between certain details of pollination and the need to represent those details in order to show pollination; and (c) by presenting this information as a series of choices to Chad, and then allowing him to choose how to implement them, Mrs. English allowed him to maintain agency and ownership of these representations, as well as allowing him to construct his own understanding about why these particular features should be represented.

This exchange also highlights the importance of viewing students' representations of "content" as a form of practice (cf. Roth, 1997) that in this case includes an understanding of the norm that defines the need to represent important details, and the acknowledgment of what those important details are. Mrs. English presented the important details not as important parts of the plant (though that is something that was discussed in the past), but as important to pollination, the referent for this activity. This is most salient in line 16 when she asked, "If we don't have a pistil can we have pollination?" In this way, we argue that she was reenforcing not only the content, but the representational norm which acknowledges that important details in the referent need to be represented in order for a representation to be accurate. From the interviews we know that the focus on including certain details and their relationships appeared to replace the students' use of personal preference to guide their representational choices.

### Episode 1: Summary

This first episode highlights a number of the mediators that students encounter as they create their representations. These include their peers, the physical environment, classroom norms, and the constraints of the materials that they are using to create their representation. In addition, it also highlights the way in which students are frequently forced to negotiate these various mediators in local interaction in order to create a particular representational performance. A significant result of this negotiation in the current example was a shift in how Chad framed his representational dilemma. Negotiating a new frame (e.g., not having to make the bee look and act like a real bee for aspects not directly related to pollination) ultimately allowed him to reach a solution. In addition, we examined the ways in which the social and socioscientific norms may have influenced, and been influenced by, these particular local interactions. Finally, this example helped illuminate the way in which the teacher made use of her access to the representational process to help mediate Chad's understanding of the material. In the next episode we identify several other mediators and their role in students' representational activities.

### Episode 2, Excerpt 3: Reminders as Openings for Negotiation

Episode 2 took place during the postactivity sequence, 6 weeks after Episode 1. Mrs. English assigned the students to draw pollination in a way that it could be understood and identified as pollination simply by looking at it, without the need for the students to explain it. The students in this episode (see Figure 3) are Alex (7 years, 4 months old), Talia (6 years, 7 months old), Lynn (6 years, 2 months old), Michael (6 years, 7 months old), Aurora (5 years, 7 months old), and Shuman (6 years, 2 months old). These students make up the entire second case-study group. The students worked on this drawing for one class period. Each student was given a piece of paper on which to draw, and access to pencils and colored pencils for their drawings. References on flowers and pollination were made available throughout the classroom as in the first episode. In addition, a book with images of flowers and insects was on the table in front of the students, as was a live moth in a plastic jar that Alex had brought from home (see Figure 3). The students were asked to create their drawings individually, but they were allowed to talk while they worked. At the time our analysis begins, the students had already been working on their drawings for approximately 12 minutes.

As noted in our analysis of Episode 1, students' representational activities are heavily mediated by their peers both directly, as their peers offer recommendations or critiques, and indirectly in the form of the various norms of behavior that have been established within the classroom. These norms can sometimes directly mediate students' behavior, as they appear to remember them, and sometimes play an indirect role in influencing their activities as their peers remind them of the various norms. The students in Episode 2 followed a similar pattern in taking advantage of the opportunities that open interaction affords to remind each other of the representational norms for the current activity—drawing pollination. The focus of our analysis for this episode is on the role that these reminders play in aligning students with the classroom norms that are still developing and stabilizing. We argue that the way in which these norms and the content introduced by the teacher mediates students' activities can explain the shifts that we noted in the students' interview responses—more content details, less individual preferences, and an increase in audience awareness.


**Figure 3.** Students of Episode 2 creating their drawings in open interaction.

Excerpt 3

| | | |
|---|---|---|
| 1 | Alex: | Remember we have to do the parts of the Rose. (.) |
| 2 | Talia: | (Talia from Lynn turns to Alex just before saying) I know. (4.5) That's |
| 3 | | why I'm erasing my (.) hummingbird. Because I don't like it and- |
| 4 | (?): | (inaudible) |
| 5 | Talia | What? |
| 6 | Alex: | Can I use your eraser Lynn? |
| 7 | Lynn: | Sure, in just a minute. |
| 8 | Alex: | One second? |
| 9 | Talia: | Here (she finishes erasing, and hands her eraser to Alex) |
| 10 | Lynn: | I said a minute. |
| 11 | Alex: | Ok, I don't need it now. |
| 12 | Talia: | I already finished mine. |
| 13 | Alex: | Remember Ms. English said not fast work. |
| 14 | Talia: | I'm not doing (fast) |
| 15 | Lynn: | Me neither. |
| | | (quiet work, as well as a brief exchange between Alex and Michael about Michael's representation, which he appears to be unsatisfied with) |
| | | (38.0) |
| 16 | Lynn: | You can copy my hummingbird (leaning towards, and looking at Talia) |
| 17 | | (Aurora leaves the table here) |
| 18 | Michael | (Resumes erasing here, and continues past the end of the episode with only a |
| 19 | | brief pause below) |
| 20 | Talia: | I don't really want to copy a hummingbird. I changed my mind. I'm actually |
| 21 | | gonna make a butterfly. |
| 22 | | (3.6) |
| 23 | | Remember Butterflies can (sip from the seed) if they want to. |
| 24 | Lynn: | (yeah and I'm not making) the rose (standing up and holding her drawing |
| 25 | | out) |
| 26 | Talia: | Yeah, but I'm making a rose so I'm- |
| 27 | Alex: | (Or) we could make a wood pecker. |
| 28 | Lynn: | It's not a wood pecker. |
| 29 | (?): | [I'm making a flower.] |
| 30 | Michael: | [A wood pecker.] A wood pecker isn't a pollinator. (Michael pauses in his |
| 31 | | erasing to gesture with both hands as he says this) |

There are two norms concerning representational activities that are salient in the current episode: the socioscientific norm to represent certain details of the referent in the representation, and the social norm of doing careful work when creating a representation. In contrast to the previous episode, the reminders in this case came from the other students although they often used reported speech to invoke Mrs. English as the source of a norm. For example, in line 13 of Excerpt 3, Alex attributed the norm of not doing fast work to Mrs. English. This shift from teacher regulation to self-regulation and peer regulation is consistent with the notion that the students were beginning to appropriate the classroom norms established by the teacher.

At the beginning of Excerpt 3, Alex glanced over at Talia's work. He then reminded Talia to represent all the parts of the rose (Excerpt 3, line 1). This reminder and the others to follow create openings for students to show their alignment with the norms of the community and to negotiate how the norms and constraints can be coordinated in the representations they

are currently producing. Talia does not respond to Alex. However, her final drawing does include the pistil and stamens, features that would normally be hidden behind the rose petals. The second unsolicited reminder found in this episode occurred when Alex told Talia that they are not supposed to do "fast work." Not only did Talia reply that she was not doing fast work, but Lynn also took this opportunity to align herself with the norm by saying that she too was not doing fast work (line 15). It is possible that Talia simply did not want to be accused of doing something wrong by Alex, and so would have contradicted him no matter what he said. However, the additional unsolicited claim by Lynn that she was also not doing fast work serves as evidence that Alex's suggestion, which was directed at Talia, was heard by some of the other group members, and that at least one of them, Lynn, agreed that it was a norm and made sure that it was clear to everyone that she was following it. This type of interaction where the students remind each other of the requirements of the activity (such as representing details) is common throughout the data, pointing to one way that norms are made apparent to the students that does not involve the teacher directly. We argue that these alignments therefore serve to do more than simply allow Talia and Lynn to demonstrate that they are doing what they are supposed to. Rather, by making these declarations, the students are demonstrating that they recognize that this is the correct behavior, thereby reenforcing it as a norm within this class.

It is also worth noting that this notion of not working fast comes up several times in the interview data, including Talia's description of this particular representation, under the Accomplishment code when she says that one of the things she liked about her drawing was that she "[made] it as good as possible." This shows that while "not working fast" may appear to be simply a social norm, it has consequences for the students' representational activity and the students utilized this norm to evaluate representations in the postactivity interview. From this we can infer that evaluating representations may require an understanding of the socioscientific norms that define an adequate representation, as well as an understanding of the social norms that define proper participation in the community.

A third unsolicited reminder to use only animals or insects that are pollinators (i.e., a socioscientific norm of factual accuracy, typically coded as Details or Relationships within the interviews) occurred at the end of Excerpt 3. This part of the interaction began when Lynn held up her drawing and declared that she was making a rose while leaning over the table to show her drawing to her peers (line 36). Alex and Talia both responded in slightly different ways. Talia began to explain that she was making a rose, but was cut off by Alex, who responded that they could make a woodpecker (line 39). It is possible that Alex was simply making this comment and not responding to Lynn's rose display. However, the responses to his suggestion show how the other students evaluated it as incorrect regardless of his intent.

Michael took the opportunity to assess this suggestion in terms of the content being studied—pollination—by pointing out that a woodpecker is not a pollinator. Michael demonstrated his perception of how the violation was important by stopping in his activity and gesturing with his hands into the space to underscore his assessment before returning to his erasing. It is unclear whether Alex intended to draw a woodpecker, and in fact we know he ultimately drew a moth. However, by introducing this suggestion into the public space, the possible choice of the pollinator was evaluated with respect to the content domain by the other students. This type of feedback seems to be consequential for the specific representational choices, establishing and maintaining the importance of certain aspects of the content, and demonstrating the possible impact of making these suggestions in open interaction where the culture appears to allow for feedback from other students.

### Episode 2, Excerpt 4: Open Interactions with the Teacher

Shortly after Excerpt 3, the teacher came over to the table and asked Aurora a series of questions about her drawing. Excerpt 4 involves this series of questions from Mrs. English with input from a number of the other students at the table, revealing some additional ways in which students' ideas about representations are shaped by and in open interaction.

Excerpt 4

| | | |
|---|---|---|
| 1 | Mrs. English: | (to Aurora) So, your pollinator is a moth? |
| 2 | Aurora: | (no, it's) a butterfly |
| 3 | Mrs. English: | Right, and where is it going? |
| 4 | Aurora: | Right and I forgot to put the part |
| 5 | Mrs. English: | So where is it- which one—where is it starting? |
| 6 | | Is it going to down (in this part)? |
| 7 | | What does it want? (2.5) |
| 8 | | What does it really want? |
| 9 | | What does it like to eat? |
| 10 | (Michael): | Nectar |
| 11 | Mrs. English: | Show me where it is? (points at drawing) |
| 12 | | That's the stigma, that's the um sticky stigma. Is that—Where is the |
| 13 | | nectar of the flower? |
| 14 | Talia: | In the way down inside here (leaning across the table to point it out) |
| | | (Shuman also points. Mrs. English then points to the general area where Shuman pointed) |
| 15 | Mrs. English: | And then it's gonna get some of this pollen on it. |

This example shows that not only are students monitoring each other when they are engaged in small group work or parallel activity, but they are also attending to other students' instructional interactions with the teacher that have no direct bearing on their own activity. In line 14 when Talia leaned over to point out where the nectar should be indicated on Aurora's picture, it is clear by the timing of her utterance—right on the heels of the teacher's question—that she had been monitoring the teacher's conversation with Aurora. At the same time that Talia pointed to the drawing, Shuman pointed to another part of the drawing in answer to the same question. While it is unclear from our record exactly where they are pointing, it seems plausible that they are each pointing out the location of the nectar in the drawing. Mrs. English's nod appears to validate their contribution as she continued her discussion in line 16. An obvious implication of this interaction is that the representational performance of each of the students is not individual; Aurora created the representation, but needed another student to help answer an important content question around it. In contrast, Talia and Shuman were able to answer the question, but made use of Aurora's representation to do so. If this is a fair interpretation, than what appears to be an individual student's representational competence (the ability to describe the content using a representation) is responsive to the material context in which it is displayed. Furthermore, the material context may include other people's representations. Put differently, students' representational competence is distributed across multiple people and tools (cf. Hutchins, 1995).

The fact that Talia and Shuman made use of Aurora's representation to answer the question directed at Aurora was also telling. It shows, implicitly, that they both considered her drawing

a valid representation of pollination that could be used to answer questions. It also shows that they recognized that Mrs. English might have been looking for an answer grounded in Aurora's current work. Finally, it shows that in contrast to Excerpt 1, at this point in the unit the students did in fact distinguish between the process of creating the representation and the representation itself. Specifically, because Aurora could not answer the question about what the pollinator wants, we might assume that she did not consciously include it in the representation. Talia and Shuman, however, appeared to separate Aurora as the creator from her own representation as they evaluated the representation for where the nectar should be in relation to the other parts of the flower and used this in answering their question. In contrast to Excerpt 3, the students' knowledge of Aurora's role in creating this representation does not appear to have impacted their evaluation of it. It appears that students' evaluation of a representation is mediated by their knowledge of its creation.

### Episode 2 Summary

In this episode, we demonstrated how the norms, and in particular the representational norms of this classroom, were continually demonstrated as legitimate by the students and that this process may contribute to the appropriation of these norms. In addition, the role of open interaction was again shown to be central to the way in which students impacted their peers' representations. Finally, we showed how awareness of the practice in which a representation is created is also a negotiated mediator. The students in this episode appeared to ignore aspects of authorship when evaluating a representation to answer the teacher's question.

## DISCUSSION

Our analysis of the students' interviews and representational activities reveals that kindergarten and first-grade students have a number of resources that they bring to bear when creating and evaluating representations. Furthermore, through interaction and negotiation with their teacher and peers in activities that focus on the construction, evaluation, and refinement of representations, students developed a much richer sense of what makes a good scientific representation within their classroom community. However, this process of socialization into a particular definition of what counts as a good representation makes it problematic to truly separate representational competencies from meta-representational competencies, as students are in the process of appropriating these norms, and as the norms are themselves changing over time. Therefore, we have proposed a focus upon NeRMs as an analytic tool for examining students' representational performances and discussions about their representations within our data.

Our analysis of the interview data reveals three broad categories of factors that mediate how students in this study made representational choices; individual preferences, aspects of the local activity system, and the students' understanding of the content being studied. Each of these was also influenced by the students' ongoing socialization into the classroom norms. For example, one of the strongest norms in this classroom was the need to represent the important details of pollination. However, the details that the classroom identified as important shifted as the teacher instructed the students on new aspects of pollination (e.g., relationships between pollinators and flowers). In the early phases of this study, students frequently used their personal desires and preferences to guide their production of a representation, making choices about what to include and exclude on the basis of what they liked. As they continued to produce more and more representations of pollination, as each one of these representations was placed under the scrutiny of the teacher and peers, and as

they discussed the important content ideas in whole-class discussions, the students began to shift what was guiding their production to be more aligned with the content that the teacher was stressing.

However, personal preference never disappeared. This transformation of personal preference into the inclusion of details and relationships is particularly interesting in that it shows continuity in the students' knowledge and activity (cf. diSessa et al., 1991), which has been argued to be an important component for students as they attempt to appropriate new ideas. In some cases, personal preference appeared to be a first step in the production of a representation. What was new was that the students followed the consequences of their preferences to their logical conclusion. For example, if students chose a hummingbird because they thought hummingbirds are pretty, they would then continue to make choices consistent with the features of the hummingbird, such as choosing a deep flower rather than just any flower that they liked. In other cases, students appeared to start with the details or relationships that they needed to represent. This narrowed the problem space. They then used their personal preferences to make the final choices within that smaller space. This relationship between personal preference and content requirements will be an important area to follow up in future studies of students' NeRMs as they develop through socialization.

The mechanisms that we identified in our case-study analyses—observation, eliciting and providing assistance, reminding others of the community norms, interrogation of an in-progress representation by an adult—were all social mechanisms that mediated the representation's final form and the students' understanding about what was important about the process of representation production. Furthermore, the analysis of these mechanisms appears to complement the trends identified in the interview analyses. For example, in the first Episode we saw how Chad had to contend with what appeared to be a personal preference regarding the bee and his understanding of the materials he had at his disposal, as well as the other activity constraints. His peers, along with the teacher's reminder, allowed him to negotiate this tension by changing the problem he was attempting to solve. However, when asked during the preinterview to explain why he put the bee where he did, Chad said, "I didn't know how to make it like, be in the air [. . . ] so I made it on the flower with its tongue sticking out trying to get the pollen." Therefore, while Chad's explanation highlights the dilemma that he encountered when attempting to place the bee in the air using clay, it is the analysis of his actual interactions with his peers that reveals the way in which he was able to negotiate and therefore ultimately solve this problem.

In addition, the social mechanisms identified in the case-study analyses appear to be an important part of the process through which students appropriate the classroom representational norms. For example, the various reminders that students offered to their peers in the second episode may be an important part of how students try out their new set of representational mediators in the public space, help to ratify the norms as normative, and how the students help each other to remember and eventually appropriate the various norms.

One possible concern that may arise from this interpretation of the data is that students are not understanding the rationale behind the representational norms because they are being handed down from the teacher, and not arising solely from students' cognitive conflict and reflection. However, we see two compelling reasons in our data that counter this concern. First, the teacher often presented the norms as integral to showing pollination, not simply following directions. For example, rather than simply stating that students needed to include "details" in their representations, the teacher often asked students if it was possible to understand pollination with only one flower, and they came to respond that two were necessary to see that the bee had to carry pollen from one to the other. In this way, the norms were made meaningful for students as they were being instructed and were tied to

the types of reflection that we argue facilitated their ability to appropriate and then employ these ideas. One question for future studies, however, will be to examine whether there are differences in how well students appropriate norms that they see as solving a problem they discovered on their own (cf. Enyedy, 2005), as opposed to one presented in this way by the teacher, and whether there is a difference in the way they continue to employ these norms. A second reason that we believe that students were in fact appropriating these norms—and not just parroting them—is that in the postinterviews they were able to elaborate and use these rationales. For example, in the later activities, students often included all of the necessary details of pollination. When evaluating the comparison representations in the postinterview, many of students remarked that the author of the comparison representation had made a mistake by omitting these details and including a third flower, which was unnecessary and therefore confusing.

Our emphasis on social interaction and socialization into a community should not be taken to imply that we need to abandon analysis of the individual and what competencies, goals, and knowledge they demonstrate. On the contrary, without considering what the individual student brings to an interaction, we could not make sense of our data. For example, it is hard to imagine how we could understand the role of personal preference without some attention to the individual who has that preference. However, what stands out for us in our data is the primacy of negotiation and how this negotiation mediates what gets represented and the sense that the students make of their own activity. This means that in a negotiation of a representation, an individual's goals, knowledge, and existing competencies come into contact with and are transformed by the norms of the community, divisions of labor, other people's ideas, the tools at hand, and the contingencies of the situation. It is this mix that mediates what is produced. Given the relevance of these ongoing negotiations, we have developed the notion of NeRMs to understand the development of MRC in the context of 5- to 7-year-old students engaged in science. This term highlights both individual agency and social negotiation in the students' representational decisions as well as the way that these negotiations mediate what the students appropriate about what makes a good representation. The notion of NeRMs captures the idea that students' representations are created in practice, and make use of a number of different mediators including norms for what needs to be represented, and resources such as how to draw or sculpt with clay. At times, these mediators are in conflict, or do not seem relevant, and students appear to respond to local contingencies in making their choices. Like MRC, the notion of NeRMs is intended to honor the resources that the individual student brings to a representational activity, and places those resources and competencies in the context of social norms and practices. The point of introducing this new perspective is not to claim that the social context needs to be given primacy over the individual as the unit of analysis. Rather, like all theoretical perspectives, each perspective focuses attention on different aspects of the phenomenon being observed and is more or less useful for different aims. We argue that a perspective that focuses on NeRMs is a productive lens with implications for how to organize classrooms to produce what has been referred to as MRC. Because it provides an analytic lens that can be used to trace the origins of various components of MRC within a given classroom, it provides valuable insight into how to foster their development.

We see several related implications of this work for practitioners. First, our data reveal a potentially important role of personal preference in scaffolding students developing an understanding of new content through representational activities. By promoting personal choice in the students' representations, the teacher who we collaborated with created an entry point that facilitated students' ability to create their early representations without the need to mandate the inclusion of content details that they did not yet fully understand. This appears to have allowed the students to focus on representing the aspects of pollination that

they currently understood, while also providing a sense of ownership and individuality for their representations. The possible importance of allowing this kind of personal preference in students' representations is further demonstrated in the way that the students continued to anchor their content-related choices within personal preferences even after they had full access to the content details, providing what appeared to be an important sense of ownership in their own work.

The inclusion of personal preferences in representations is a specific case of a more general implication that classroom norms can be carefully selected and promoted to pave the way for instructional goals concerning both representational competencies and representational or meta-representational competencies. In the current data, the development of a norm for including details in a representation appears to have played an important role in how students both learned and represented pollination. This was, no doubt, due in part to the fact that the specifics of this norm changed over the course of the class as the teacher instructed the students in additional content details and relationships that were then included in the students' representations. Therefore, we argue that it is not any one specific norm that is developed to foster more productive representations but a constellation of them.

Another set of norms that we observed which hold some important implications for classroom practices were the norms surrounding open interactions, and students' opportunities to work both individually and in groups, and their ability to discuss their representations with each other. As we identified above, students' individual work afforded them the opportunity to explore their current understanding of the content and negotiate for themselves how to represent it, given the current task constraints. However, their ongoing work in open interaction also afforded them valuable opportunities to seek assistance from their peers, and to remind each other of the different norms such as working carefully and including details. As we argued above, these reminders serve an important role in allowing students to align themselves with the norms as well as refreshing each other's memory—to practice the practice. Therefore, a balance between individual and collective representational work, supported by a set of norms that encourage students to discuss their representations, appears to have been an effective mix in the current data.

The choice to provide both individual and collective contexts for representational activities is related to an additional implication for instructional designers. Designers need to conduct a careful analysis and selection of the mediators for students' representational activities in order to choose those mediators that best support the instructor's learning goals. As mentioned above, selecting the norms and social context for students' representational tasks has clear benefits. In addition, different activity structures clearly lead to very different outcomes. For example, we found that the greatest amount of debate and on-task discussion between students occurred when they were asked to create one representation as a group. In these cases, there were often lengthy debates concerning what should be represented. At times, however, these debates were reduced to issues of coordinating work that may have distracted the students from the representational task at hand. Similar to the activity structure, the physical mediators also play an important role in the various representational tasks. As we saw above, the use of clay and wire in the preactivity appears to have forced Chad to confront some questions about the three-dimensional nature of pollination. However, it may also have been somewhat distracting for Chad as he focused on how to put the bee in the air with the given materials instead of simply being able to put it there as he might have done in a drawing. We argue, however, that Chad was ultimately able to appropriate the norms and details of pollination because he engaged in a sequence of activities with various mediators that allowed him to continually develop his understanding.

Finally, an important role for NeRMs in classroom practice may be the way they help to illuminate students' understanding in informal or formal assessments. While we do not

have any data concerning formal assessments based upon this framework, we were able to examine the way in which the teacher who we collaborated with modified her instruction in response to informal formative assessment of students' representations. In fact, her choice to include a focus on the audience of a representation in the introduction activity stemmed from the fact that our preliminary analysis of the preinterviews revealed that the students had developed a norm of assuming that they could explain their representations to the teacher' and so they did not need to stand on their own. Simply examining the students' finished products without probing their ongoing practice would not have identified this trend that the teacher felt was somewhat counterproductive.

Further research into the process through which students negotiate, appropriate, and make use of various mediators in their representational activities is certainly warranted. In particular, it will be valuable to examine the link between the ways in which students appropriate these various mediators, and their use. This will help to answer the question of whether or not students make different use of these mediators if they take a more active role in defining them. For example, is it enough that the need to represent the details of pollination in a clear manner arose from discussions with the teacher, or would students make different use of this norm if they engaged in activities that instead prompted them to define this need for clarity on their own? Finally, it will be important to more closely examine the role that these types of NeRMs play in students' appropriation of the content through representational activities—to what degree does creating "better" representations of pollination lead to a deeper conceptual understanding of pollination?

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