Kindergarten and First-Grade Students' Representational Practices While Creating Storyboards of Honeybees Collecting Nectar

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Abstract: A productive approach to studying the role of representations in supporting students' learning of science content is to examine their representational practices. The current study examines kindergarten and first-grade students' representational practices in a similar context—the creation of storyboards—both before and after a curricular intervention in order to highlight those aspects of their practices that changed while engaging in a superficially similar task. Analysis of the students' storyboards reveals considerable improvement after the intervention. Analysis of the students' practices as they changed over time is also presented by examining the students' interactions, with a focus on their discussions of the science content and the representations themselves.

There is no doubt that students' ability to create representations such as drawings and graphs is central to their ability to learn science in school (DiSessa, 2004; DiSessa, Hammer, Sherin, & Kolpakowski, 1991; Lehrer & Schauble, 2006). One reason for the centrality of representations in science classrooms is that specific representational forms can help students more easily engage with and communicate complex ideas (Roth & McGinn, 1998). For this reason, representations are also instrumental in the work of professional scientists (Latour, 1988; Lynch, 1988), and thus many attempts to teach students how to engage in authentic science necessarily include helping them to create representations. After all, students do not always create representations that are immediately productive for learning and expressing science content. Rather, students need support in order to create productive and accurate representations regardless of whether they are being asked to create canonical representations (i.e., graphs) or invented representations (i.e., drawings or diagrams from observation). One method that has been used to examine the way that the students' context can support their creation of representations is to study students' *representational practices* as they engage in creating and refining representations in science class. The practice approach highlights the relationship between students' representational actions, their knowledge of the content, and the features of the context that enable and constrain those actions (Danish & Enyedy, 2007; Hall, 1996; Roth & McGinn, 1998).

Prior examinations of students' representational actions from a practice perspective have proven effective in several accounts of how representational practices contribute to or explain student learning within science and math (c.f., Cobb, Stephan, McClain, & Gravemeijer, 2001; Danish & Enyedy, 2007; Hall, 1996; Hall & Rubin, 1998; Roth & McGinn, 1998). However, there are two key gaps in the current literature that this paper aims to fill. First, examinations of students' representational practices typically focus on the way that these practices change in different contexts. This is, in part, to examine how students' movement through a range of representational activities supports them in learning new content. While this is a fruitful approach, it does not allow for a systematic comparison of students' practices as they change over time with respect to a single representational form. Second, this literature largely overlooks the representational practices of early elementary school children (for some exceptions see Danish & Enyedy, 2007; Lehrer & Schauble, 2000). Rather than neglecting the representational practices of young children, we argue that they are a crucial population to study because the practices that students develop early in their school careers will be important in supporting their later science and representational activities. Moreover, early elementary students spend a great deal of time learning by drawing, sculpting, and enacting their ideas in science class, and so it behooves us as a field to better understand these processes in order to inform research and teaching with representations.

This paper aims to begin filling these gaps in the literature by documenting the representational practices of 42 kindergarten and first-grade students in service of learning how honeybees collect nectar. The students were asked to create storyboards at two points in time: before and after a curricular intervention where they learned about honeybee content and were also encouraged to request and provide representational feedback (for the larger study upon which this analysis draws see Danish, 2009a; Danish, 2009b). First, to ground our discussion of the students' representational choices, we present a brief analysis of their representations (the storyboards) to highlight the fact that these did in fact improve over the course of the study. Then, video of students' interactions were analyzed to document the students' representational practices by identifying what their discourse revealed regarding the issues that they saw relevant in their representational practices. Specifically, their talk was coded along multiple dimensions to identify the prevalence and circumstance of talk about the science content and the representations themselves.

Representational Practices

Simply put, practices refer to the patterned way of acting that people develop over time (Lave & Wenger, 1991). More specifically, Hall and Rubin (1998) further define *representational* practices as "making, using, and reading conventional representational forms," (p. 228). Hall and Rubin also caution us that these representational practices are "less stable and more detailed than many textbooks or studies of instruction presume" (ibid). The present study responds to this concern by documenting the details of students' representational practices as well as examining the process through which these practices change.

Examining Representational Practice.

One hallmark of the practice approach to studying students' actions is that it recognizes the importance of context in shaping those actions (c.f., Roth & McGinn, 1998). To this end, most accounts of students' practices tend to at least implicitly recognize that there are features of the practice that are relatively stable across moments, and features that are highly dependent upon the moment being observed.

Stable aspects of students' representational practices. There are two ways of explaining stability, or observable patterns in students' representational practices. The first is to recognize that there are local social patterns, or norms that are stable within a particular setting. The second is to assume that individual participants "carry" the necessary knowledge across moments. Cobb et al. (2001) refer to the social aspect of this equation as norms, and the individual aspect as a psychological correlate, and argue that the two are mutually co-constructed and cannot be separated. Simply put, each individual has certain beliefs and knowledge about the practices and the content to which they refer, which include an understanding of the social norms surrounding it. At the same time, the social norms have grown out of and account for individual knowledge of the local participants. By definition norms are non-deterministic; students may or may not selectively follow them though one can typically identify norms by the way that participants mark their violation (Cobb, et al., 2001; Danish & Enyedy, 2007; Hall & Rubin, 1998).

In related research, diSessa and his colleagues identified "meta-representational competencies" which refers to students' understandings that apply across multiple representational forms, such as a belief in the need for parsimony (DiSessa, 2004; DiSessa, et al., 1991). Furthermore, these competencies, they argue, develop over time as students engage in representing in school (and other) contexts (Sherin, 2000). While these two approaches to locating stability in students' representational practices—the one focused on the social norms, and the other upon individual competencies—come from different theoretical perspectives, the result is the same; they describe patterns in how students engage with representations and suggest that these patterns, which are learned over time, have important implications for what students do with the representations that they encounter. Thus, it is important to document the patterns in students' representational actions, regardless of whether or not they appear to originate in social norms or individual preferences and competencies.

The role of context in representational practice. Of course, students' representational practices are also defined by their context of use, which may be defined in terms of the nature of a specific representation, of the task, or even of the other people present (DiSessa, et al., 1991; Hall & Rubin, 1998; Roth & McGinn, 1998). For example, students may not assume that a representation needs to be self-explanatory when they know that their teacher will allow them additional time to explain it further (Danish & Enyedy, 2007). There is, however, a reciprocal relationship between practices and context; individuals are presumed to see the context differently as a result of their changing practices. In fact, many of the studies described above rely on this to examine how students developing practices, combined with new contexts, can lead to key content learning. Therefore, in order to document students' representational practices, we attempt to identify those aspects that are relatively stable, the representational context, and the interaction between the two.

Documenting Representational Practices

Traditionally, examinations of representational practices have focused on how they change over time along with shifting instructional activities. Researchers then identify students' practices by examining talk (and actions) as the students engage in creating, debating, and modifying representations. Hypotheses are then developed regarding what types of behavior are normative. These are vetted against the corpus of data to look for seeming violations of those norms (for an in-depth description of one such approach see Cobb, et al., 2001). This approach makes sense, given that the goal of these prior studies was to understand how specific practices, when paired with specific instructional exercises, resulted in students learning about the content being studied. Unfortunately, a side-effect of this approach is that these studies provide considerably less guidance to researchers and teachers whose aim is to support more general representational activities across a range of content domains. Furthermore, while patterns in the practice are described, it is difficult to distinguish patterns from the context in which they are visible for the very reason that the researchers are shifting those contexts in order to pursue specific instructional goals. For these reasons the present study aims to examine students' representational practices in a relatively stable context—the creation of storyboards. Of course, as students' practices shift students may be expected to relate in different ways to a superficially similar context. However, by holding the task stable, we are able to gain a richer understanding of the inter-relationship between the students' changing practices and the context of their use. Finally, by shifting our focus away from the process through which students' representational practices support (or not) their learning of specific content topics, we are able to more thoroughly document the entire range of their practices.

What do we know about young children's representational practices?

Well before entering kindergarten, students are able to produce representations and understand their symbolic functioning (DeLoache & Burns, 1994). Studies have also shown that young children are aware of the context of their representational choices, and can adjust their interpretation or creation of a representation in response to their audience and the context (Callaghan, 1999). In fact, it was even demonstrated that kindergarten and first grade students appeared to recognize and balance between multiple competing influences on their representational choices including individual preferences, local norms, and the affordances of the immediate context (Danish & Enyedy, 2007). Furthermore, it has been demonstrated that young students are able to develop a rich sense of the requirements of a model for scientific activity, and to adjust their models accordingly as they engage with learning new content (Lehrer & Schauble, 2000). In short, there is reason to believe that young children are capable of rich and elaborate representational practices, and that these practices influence the role that representations play in supporting young students in learning about science content.

Methods

The data presented in this paper comes from part of a larger study known as the BeeSign study, a 10-week curriculum intervention described in detail elsewhere (Danish, 2009a, 2009b). However, the prior analyses examined student content learning based on pre- and post interviews and primarily focused on the classroom intervention. The present study extends this work by examining the storyboard activity administered before and after the larger study. The study as a whole, and the storyboard in particular, will be described below.

Participants

This study took place with two mixed-age kindergarten and first-grade classrooms (most of the students were between 5 and 7 years old) in a progressive California elementary school. The school as a whole has a range of family incomes from $35,000 or less per year to $250,000 or more per year with a demographic composition of approximately 47% Caucasian, 27% Latino, 13% African American, and 13% Asian. There were 42 students who consented to participate in the study (22 boys, 20 girls).

Procedures

The students in this study participated in the BeeSign curriculum as their science curriculum for over 10 weeks. There were typically two one-hour-long sessions per week, for a total of 19 sessions. Over the study, the students were taught about how honeybees collect nectar through a series of inquiry and representational activities. In the representational activities, the teachers encouraged the students to provide and solicit feedback from their peers.

The students began the study by engaging in a pre-test, followed by the storyboard activity to be described below. They then engaged in the curriculum activities, followed by a final storyboard activity and then a post-test interview. The interviews were scored in terms of students' understanding of honeybees in terms of the structure, behavior, and function of the system based on the work of Hmelo-Silver and colleagues (2004) who had documented that novices tended to focus on the superficial structures and behaviors of a system at the expense of the functions. The students in the BeeSign study showed statistically significant gains from the pre- to post-interview in terms of the structures, behaviors, and functions that they described (Danish, 2009a, 2009b).

The storyboard activity

The present analysis focuses on the storyboard activity that took place both before and after the curricular intervention. During this activity the students were divided by the teachers into small groups of 3 to 6 students who sat together at a table. One half of the groups remained stable from the pre- to post- test, and the other half did not because one of the two teachers chose to allow the students to form their own groups in the post-activity. At both time points the students were asked to draw a storyboard about "how bees get food" and were shown how to use a storyboard to represent a series of steps in a process. The students were given a template that included 4 boxes in which to draw the storyboard, with several lines beneath each box in which they could write descriptions of the images. The students were allowed to talk and solicit feedback from their peers. However, the teachers did not actively request this (as they had during the curriculum intervention) in order to capture how frequently the students did this of their own accord. There were 6 groups videotaped at each time point, but only 10 of the groups (5 in the pre condition, and 5 in the post) had audio and video that was of high enough quality to analyze the students' work. On average, the students took 40 minutes to complete the task.

Students' talk during the storyboard activity were transcribed and coded along several dimensions for a total of 2361 unique utterances. An utterance was defined as one breath group, or roughly one sentence. The science content codes identified honeybee structures, behaviors, and functions (Hmelo-Silver & Pfeffer, 2004). The other coding categories (described below) were developed from student talk using a grounded approach. Inter-coder reliability reached 85% agreement for 24% of all coded utterances.

To analyze the actual storyboards that the students created, a list was made of structures and behaviors based upon the pre- and post-interview-scoring rubric. We then amended this list by adding any additional structures or behaviors that were consistently mentioned in the storyboard videos, such as the fact that bees have 6 legs. Credit was given either for clearly identifiable visual features, or for references in the writing that students had included beneath the images. Two researchers coded each storyboard independently, and then compared their codes. Differences were negotiated until resolved so that the storyboard scores represent 100% agreement. These scores did not include a number of implicit features that were present in many of the post-storyboards, such as a pattern of showing the bee flying to the flower and then back to the hive. While these were technically accurate, it was difficult to attribute them to a deep understanding of the content. Also, we did not deduct points for inaccuracies such as a bee being labeled as a King bee, which primarily happened during the pre-test. Therefore, any reported gains are actually quite conservative.

Results

Storyboard Results

The mean score for a storyboard increased from 1.20 points to 5.55 points from the pre- to the post-activity (N=34 due to student absences). This increase was statistically significant: $t(34) = 11.115$, $p < .01$, two tailed. Some of the most common features that students were given credit for were the inclusion of 3 distinct body parts, the inclusion of 6 legs, and the presence of the proboscis. Figure 1 depicts representative bee drawings from the pre and post-test storyboards. The bee on the left would not have received any points while the bee on the right would have received points for having three body parts, a stinger, six legs, a clearly identifiable proboscis, a clear compound eye, and the pollen basket. Combined with the interview results referenced earlier, these findings suggest that not only did the students learn about how honeybees collect nectar over the course of this study, they also demonstrated this learning in their storyboards. With this learning as a backdrop, we now present the analysis of student talk while creating the storyboards. In particular, we will focus on several of the shifts in talk from the pre- to post-test condition as they coincided with these dramatic increases in what features the students incorporated into their storyboards.

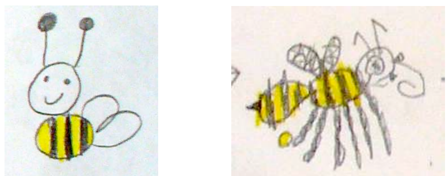

Figure 1. An example of a bee from the pre-test (left) and from the post-test (right).

Representational Practice Results

The first analysis we performed was to determine how much of students' talk throughout this sequence of activities related to the content being studied (either science talk, or the representations themselves). Each utterance was then coded as belonging to one of four categories: Science and Representation, Instrumental and Procedural, Spelling and Heading, and Off-topic (see Table 1 for descriptions and frequencies).

Table 1: Student utterances while creating their storyboards

	Science and Representation	Instrumental and Procedural	Spelling and Heading	Off-topic
Description	Talk about the science content (honeybees) or the representation.	Talk about the procedure and materials such as crayons, or the storyboard template	Sounding out letters, or asking someone how to spell words	Talk about lunch, clothes, parents, pop-culture, etc
Utterances (N=2361)	869 (36.8%)	802 (33.9%)	211 (8.9%)	479 (20.2%)

While our analytic focus for the remainder of this paper will be on the 36.8% of the talk where the students discussed the actual science content of the curriculum unit, or their ongoing representations, it is important that we not dismiss the fact that there remains an additional 42.8% of talk which was on-topic, and central to the students' work. This is important because we do not want to give the impression that the students were silent except when addressing the content. Nor should one consider a noisy classroom, in which many students are discussing issues other than the content being covered, problematic. Rather, much of this talk may be central to students' ability to engage with their ongoing work. Furthermore, we often noted that even when silent or discussing off-topic issues, students were frequently seen drawing. In other words, despite being quite revealing about students' understanding of content, on-topic talk is not the only predictor of how effectively the students were creating their representations.

What aspects of the science content do students discuss as they create their storyboards?

In order to better understand the relationship between students' social practices while representing and the content being studied, we examined the science content of their talk. We first coded the students' science talk in terms of whether it referred to the structures, behaviors, or functions of how honeybees collect nectar. Our hypothesis was that students would talk primarily about structures and behaviors as this mirrors previous findings that describe students' performance when examining complex systems (Hmelo-Silver & Pfeffer, 2004). Furthermore, we hypothesized that there would be a significant increase in student talk about these features during the post-test as the students learned the content. Note that utterances were only coded if they represented a unique idea within an episode. Episodes consisted of groups of utterances around a similar topic. In other words, if a student mentioned the proboscis, and then discussed it for 5 utterances with their peer, this was only coded once in order to avoid inflating our results. Some utterances were also coded simultaneously for a structure and a behavior, or for more than one structure. Finally, note that the percentages refer to percentages of on-topic utterances in each condition, and so do not sum to 100 as there were also on-topic utterances related to representations and other issues to be discussed below. Frequency counts and examples are presented in table 2.

Table 2a: Students' science talk across time.

	Structure	Behavior	Function
Examples	Bee, hive, proboscis (e.g. "This is a bee hive.")	Searching for flower, getting nectar, performing a dance (e.g. "They're going to drink nectar from the flower.")	Survive the winter, collect nectar more quickly (e.g. "They do a dance to tell others where the honey is.")
Pre (N = 367)	106 (28.8%)	86 (23.4%)	11 (3.0)%
Post (N=502)	113 (22.5%)	34 (7.9%)	2 (0.4%)

As can be seen in table 2a, the most common type of science talk related to structures, as hypothesized (28.8% in the pre- and 22.5% in the post-condition). However, we were surprised at the fact that the percentage of on-topic science talk decreased from the pre- to post-storyboard. This decrease was statistically significant for unique counts of structure ($\chi^2(1, N = 869) = 4.56$, p = .03), unique counts of behavior ($\chi^2(1, N = 841) = 40.90$, p < .001), and unique counts of function ($\chi^2(1, N = 869) = 9.71$, p = .02). We will return to this point after first presenting some follow-up analyses.

To assess the quality of this science talk we applied three code modifiers, marking each science content utterance for whether it was scientifically inaccurate or not, anatomically detailed or not, and topically extraneous or not for the given science prompt: how do honeybees collect nectar. Note that, as before, these codes represent unique ideas within a given episode, and so these counts are somewhat conservative and again do not add up to 100% (See Table 2b).

Table 2b: Quality of students' science talk across time.

	Inaccurate	Detailed	Extraneous
Examples	Flowers contain honey, there is a king bee (e.g. "This is the king and queen bees.")	Head, thorax, abdomen, proboscis, pollen basket, (e.g. "The pollen basket's right there.")	House, trash-can, jetpack, chairs (e.g. "This is how I make a person in a chair.")
Pre (N=367)	11 (3%)	0 (0%)	19 (5.2%)
Post (N=502)	1 (0.2%)	24 (4.8%)	8 (1.6%)
$\chi^2(1, N = 869)=$	12.18, p < .001	18.04, p < .001	9.04, p = .003

Table 2b presents a somewhat different picture of students' science talk as it moves from the pre-test to the post-test, and may begin to explain why students' discussion of structures decreased despite our prediction that they would increase. While the percentage of talk featuring science structures decreased from the pre- to post-activity, the talk in the post-activity contained significantly fewer inaccuracies, more details, and fewer extraneous features than talk in the pre-activity (See Table 2b). This may also partially explain why the storyboard products in the pre-activity often contained inaccuracies, minimal details, and extraneous features, whereas the storyboard products in the post-activity presented fewer inaccuracies and many more details. In short, students' talk in the post-test was far more refined, focusing on accurate and relevant details.

To further explore the role of science talk in the students' representational practices, we then addressed the question, *How do the patterns of student talk change with respect to audience?* Despite a concerted effort to limit teacher interaction with students during the storyboard activity, students often addressed the teachers or responded to very high-level questions from teachers or other adults with very specific information. The results are summarized in table 3.

Table 3: Students' science talk across audiences.

Audience	Structure	Behavior	Function
Peer (N = 503)	99 (19.7%)	33 (6.5%)	5 (1.0%)
Adult (N = 293)	87 (29.6%)	83 (28.3%)	8 (2.7%)
Self (N = 68)	30 (44.1%)	9 (13.2%)	0 (0%)

Students were more likely to explicitly mention science structures in comments made out loud to their selves (44.1%) or to adults (29.6%), than when speaking to their peers (19.7%). Similarly, students were more likely to explicitly identify honeybee behaviors when talking out loud to their self (13.2%), or an adult (28.3%), than when conversing with a peer (6.5%). Further, students were more likely to discuss functions relevant to nectar collection when speaking with adults (2.7%), than with a peer (1.0%) or out loud to themselves (0%). This highlights the importance of the teacher in soliciting content-rich discussion from the students given that these predominated even when the teachers were intentionally limiting their discussion with the students.

What aspects of the representations do the students discuss?

To answer this question, students' representational talk was coded in two specific ways. First, it was coded in terms of whether the students were discussing what to represent, how to represent it, or why it should be represented in that way. These three categories were designed to capture the nuances of students' representational talk, and whether it engaged students in simply discussing the features of their specific representations, the method of implementing those features, or the underlying motivations and reasons behind them (Danish, 2009a).

Our grounded approach generated two further coding categories: Unspecified and Progress. Unspecified comments present an indiscriminate or vague subject (e.g. "Look at this" or "I'm doing something cool") and Progress comments refer to the students' current state of completion (e.g. "I'm on my third one," or "I'm almost done"). With respect to unspecified comments, note that while we could frequently determine the feature that the students were addressing by looking at the video, it was unspecified whether they were referring to the inclusion of the feature (the What code) or how it was represented (the How code). Prior analyses (Danish, 2009a) indicate that students focus on "what" was represented when drawing (as opposed to skits or simulations where students are more likely to discuss the "how" or "why" of their representational choices). Our hypothesis based on prior analyses is that students will primarily focus on the "what" features of representations during the pre-activity, but will shift to discussing the "how" and "why" of their storyboards more often in the post-activity. As predicted, the majority of students' talk in the pre-activity related to "what" was represented ($\chi^2(1, N = 869) = 47.13$, $p < .001$), whereas in the post-activity this talk shifted significantly to the "how" ($\chi^2(1, N = 869) = 25.47$, $p < .001$) and "why" ($\chi^2(1, N = 869) = 28.76$, $p < .001$) of the representations (see Table 4).

Table 4: Students' representational talk across time.

	What	How	Why	Unspecified	Progress	Other
Pre (N = 367)	232 (63.2%)	27 (7.3%)	13 (4.3)%	35 (9.5%)	6 (1.6%)	46 (12.5%)
Post (N=502)	199 (39.6%)	98 (19.5%)	73 (14.5%)	45 (9.0%)	36 (7.1%)	49 (9.7%)

As with students' science discourse, our goal in this analysis was to move beyond simply documenting the content of students' talk to capture the role that it played in their practices. Therefore, we further coded students' representational talk in terms of how it supported their interactions. Specifically, similar to prior work (Danish & Enyedy, 2007) we noticed that students typically engaged in assessing or critiquing each other's work. Therefore, we coded students' utterances in terms of the various ways that assessments played a role in shaping the students interactions: (a) Assessment-Seeking, (b) Assessment-Giving, (c) Assessment-Warranting, and (d) Assessment-Responding (see Table 5 for descriptions, examples, and frequency counts). Note that while we are reporting incidences of student talk in table 5, these comments often played a role in shaping students' representations, causing them to add, remove, or change the features of their drawings in response to the issues raised, even when the student making the change was not directly addressed (for similar examples see Danish & Enyedy, 2007).

Our statistical analysis reveals that students are significantly more likely to engage in assessment related interactions during the post-activity than in the pre-activity for our first three coding categories: (a) Assessment-Seeking ($\chi^2(1, N = 869) = 3.88$, p = .048), (b) Assessment-Giving ($\chi^2(1, N = 869) = 18.41$, p < .001), and (c) Assessment-Warranting ($\chi^2(1, N = 869) = 6.58$, p = .010). Assessment-Responding increased marginally from pre- to post-activity ($\chi^2(1, N = 869) = 3.01$, p < .082).

Table 5: Students' evaluative interactional moves over time.

	Assessment-Seeking	Assessment-Giving	Assessment-Warranting	Assessment-Responding
Description	Directly requests evaluation of their storyboard	Explicitly appraises their storyboard or their peer's.	Augments their appraisal with a reason or example	Replies to the given feedback
Example	"What do you think of this?"	"it doesn't have wings," or "you forgot legs."	"the stinger is suppose to be a straight line"	"I forgot to include it" or "I'm waiting to draw it"
Pre (N=367)	2 (0.5)	6 (1.6%)	2 (0.5%)	4 (1.1%)
Post (N=502)	11 (2.2%)	42 (8.4%)	15 (2.9%)	14 (2.7%)

Discussion

This study aimed to document and describe the development of a group of kindergarten and first-grade students' representational practices as they related to drawing storyboards about honeybees collecting nectar. To highlight the change in students' practices, they were examined in a similar context (creating a storyboard) both before and after having learned about the content (how honeybees collect nectar). Our goal in doing so was to examine how the practices changed over time despite the fact that the task was, ostensibly, the same. We do not claim that the participants experienced the practice as the same at both time points. In fact, our theoretical assumption is that students' knowledge of the content and representing, and their shared practices for representing have shifted, which in turn shifts the way that they engage in representing at these two time points. In other words, the students learned new practices—which include an understanding of the content, how to represent it, and how to assess representations of it—and those new practices influenced how the students responded to the stated task of showing how bees get food using a storyboard.

Our results reveal that students' representational practices include a great deal of time talking about the task requirements (instrumental talk), some off-topic talk, as well as discussions of the content and how it should be represented. Initially, we were surprised to find that the students' talk included a higher percentage of unique ideas regarding science-related structures and behavior in the pre-activity than in the post-activity. However, further analyses revealed that those ideas were less accurate, less detailed, and were more likely to include non-essential structures (e.g. ladybug, house) to the science being represented. Furthermore, students were more likely to request and give assessments during the post-activity than during the pre-activity. These are important changes in representational practices that cannot be derived simply from counting the amount of structure and behavior talk.

A practice-oriented, and heavily contextualized analysis of students' representational acts defies, by definition, generalization of the specific findings. In other words, we would not expect to see this same pattern of talk in every kindergarten and first-grade classroom. However, we believe that some aspects of this analysis are, in fact, crucial to understanding and supporting other students and contexts. First, we have shown that there may be some value in examining the set of students' representational practices as they change over time instead of simply focusing on how they relate to the microgenesis of specific content knowledge as prior studies have. Had we not taken such steps, we might have overlooked the fact that students actually talk less about the content as they continue to master it—an important finding to consider when engaging in formative assessment of students' ideas through representational activities. This kind of analysis is supported, in part, by examining tasks that appear to be similar, rather than attempting to examine a shift in practices and context at the same time. Second, we hope that by documenting the breadth of student talk as they created their representations, we have helped practitioners and other researchers to recognize the fact that even students who have moved through a curriculum in a rather successful manner do not limit themselves to discussing the content accurately and consistently. However, one shift in student practices that appears to help correct for student mistakes and persistent misconceptions is the increase in critiques and other forms of assessment followed by students adjusting their representations accordingly. Future work should look more closely at the role of such critiques in supporting students as they create representations, and examine processes for encouraging more of them.

In sum, we have attempted to provide a robust and realistic picture of the kinds of talk that students engaged in as they created representations. Our hope is that this is a starting point for additional studies of students' representational practices which aim to look beyond the microgenesis of specific content ideas to a full description of the relationship between students' representing, the content, the context, and how these all shift over time.

Endnotes

(1) Cobb et al., actually separate this discussion into several nested levels of analysis. However, for brevity, we compress them into the two components for our present discussion.

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