Unpacking the Mediation of Invented Representations

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Abstract: In this paper we compare two contexts where students were inventing representations; a 2nd and 3rd grade classroom creating a *shared* representation, and a kindergarten and 1st grade classroom creating *unique* representations. Contexts for developing shared representations are those in which a class attempts to jointly construct one representational form to solve a given problem. In contrast, contexts for inventing unique representations emphasize individual representational choices with no explicit attempt to create a shared representational form. Drawing on and comparing data from two recent studies we use the Negotiated Representational Mediators (NeRM) framework to analyze young children's activities oriented towards the production, evaluation, and modification of representational forms. Both cultural contexts lead to a convergence toward normative representations as well as continuing to diverge in the form of individual acts of creativity and agency. We argue that despite these similar trends, the different contexts support unique aspects of representational practice.

Material representations such as graphs and diagrams play a central role in learning and doing mathematics and science. For this reason, numerous studies have examined the way in which particular representations play a role in cognition. Many of these examine the difficulties that students have understanding a normative representation, or the benefits of using particular forms of representations or representational systems (cf., Greeno, 1987; Kotovsky, Hayes, & Simon, 1985; Larkin & Simon, 1987; Turner, Wilhelm, & Confrey, 2000; Zhang & Norman, 1994). Recently, increasing attention has been paid to the role of invented representations where students create or re-invent a representation in response to some set of task demands. Activities intended to foster the invention of representations can be described as falling into two general categories: *shared* or *unique*. Contexts for inventing shared representations refer to activities in which the objective is to have the students work as a group to eventually create one shared representational form that will be used to coordinate the activity of the entire group (cf., Enyedy, 2005; diSessa, 1999). Contexts for inventing unique representations refer to classroom activities where there is no explicit goal of achieving a shared convention for the overall class (cf., Danish & Enyedy, under review). Instead, students are encouraged to create unique representations of their own. While previous work has shown the power of invented representations as well as a number of factors that contribute to the effective use of invented representations in classroom practice, we believe that some subtle but important differences that result from the different contexts for invented representations have gone unexplored. This paper proposes a new theoretical construct that illuminates these subtleties that are illustrated with examples from previous empirical research (ibid; Enyedy, 2005).

The goal of this paper will be to examine the impact of these two contexts for inventing representations—shared and unique—to highlight the different kinds of representational activities that result from the negotiation of mediating factors including the orientation towards invented representations, classroom norms, the material environment, and interaction with others. In particular, we will highlight the fact that despite seemingly different goals, students engaged in both representational contexts showed a tendency to converge upon a representation that was conventional within the classroom as well as continuing to diverge in the form of individual acts of creativity and agency. We will discuss some of the causes of this convergence and divergence, as well as highlighting some important differences in student activity that resulted from the different representational contexts. It is important to note that our goal is not to identify one context for invented representations as better than the other, but rather to elaborate the different types of practice that are likely to occur within each context, and the way in which they are elicited by the context.

Negotiated Representational Mediators (NeRM) as an Analytic Frame

The notion of Meta-Representational Competence (MRC) has been shown to be a valuable analytic tool to understand the process of inventing new representational forms (diSessa, 1999; Enyedy, 2005). MRC describes the resources that students' bring to bear across multiple representational acts, such as the ability to critique an existing representation, an understanding of the function of a representation, and even the ability to draw, which students frequently leverage in encountering new representational challenges. These resources are important both in

inventing representations and in effectively using conventional representations. Elsewhere, we have proposed to synthesize MRC with a practice-oriented notion to representational activity (c.f., Hall, 1996; Roth, 1997; Roth & McGinn, 1998), by focusing on the negotiations and mediators for a representational practice as it develops within a classroom community (cf., Danish & Enyedy, under review). This framework, which we called Negotiated Representational Mediators (NeRM), attends to the situational and interactional contexts that are under-theorized in MRC. The NeRM approach assumes that any given representational act is *mediated* by multiple factors (Engestrom, 1987). These include local norms for representation, the activity that the student is engaged in, individual understanding and preferences, the physical environment in which an individual is creating their representation, and the other people present At any given moment multiple mediators may apply to a student's activities, and may even conflict. By examining the way in which students and teachers *negotiate* these mediators, we argue it is possible to describe a rich set of resources and contextual factors that lead to representational inventions and accomplishments. The NeRM framework highlights the role of these mediators of the students' activity, conflicts or contradictions that may arise between them, and the process through which these conflicts are resolved in order to understand the students' representational practices.

Methods

Our analysis is a retrospective comparison of two independent studies of classrooms oriented towards the invention of representations where one was oriented towards creating a shared representation, and the other toward creating unique representations. The differences between these two classroom studies, which include age, task, and content domain among other factors, make it difficult to conduct a direct empirical comparison between them. However, our goal is not to directly compare these two contexts. Rather, our goal is to see the extent to which NeRMs can be applied to different contexts and the insights it provides. Therefore, the differences between the two classrooms allow for a richer set of conjectures than would two classrooms which were more similar.

First, we examine examples of inventing shared representations from a first and second grade classroom (ages 7-9) in which 22 students re-invented the notion of topographical maps (for a full treatment of this study, see Enyedy, 2005). We will refer to this classroom as the mapping classroom. The mapping unit consisted of six major activities spanning a total of seven days, for a total of approximately eleven hours. The activity we focus on here is one in which the students constructed and then mapped a city made of wood blocks. After the blocks were cleaned up they were asked what would be difficult about rebuilding the city based solely on the maps they had drawn. During the discussion the students decided that the birds-eye-view approach that they had used in their maps lead to a difficulty in identifying the height of the buildings. They then collectively developed a system to show height on their maps. The task in this classroom was oriented towards creating one shared representational form that all 22 students could employ in their maps. One of the teacher's goals was that this shared representational form be similar to the one employed by professional mapmakers.

Second, we examine examples of inventing unique representations within a kindergarten and first grade (ages 5-7) science classroom (for a full treatment of this study, see Danish & Enyedy, under review). We will refer to this as the pollination classroom. The classroom consisted of 21 students who were observed for 2 months while creating representations of flower pollination. Students participated in pre and post interviews in which they discussed and evaluated their representations and representational values. Our analysis focuses upon video data of 2 case-study groups of 5-6 students as they created their representations. The task in this classroom was for students to each create a unique representation of pollination, so long as it included the important details necessary to show pollination. Examples of these details included having two flowers of the same type showing the pistil (female sex organ) and stamens (male sex organs), and a pollinator. The students were otherwise given a great deal of freedom in selecting how to represent those details.

Analytic Approach

In order to analyze our data, we first examined the field-notes and video logs to identify instances of potential theoretical interest in the corpus of video data—those in which it appeared there was a connection between the representational context and the way in which individual students' activities were influenced by this orientation. In each excerpt, we began by attempting to identify the mediators that were relevant to the participants (Goodwin, 2000), identifying the way in which multiple mediators were negotiated in interaction, and the impact that this has upon students representational activities (Danish & Enyedy, under review). Examples of mediators include

representational norms (such as a list of details which needed to be included in the representation), the students' peers, teacher, and the physical materials that the students were using. We then traced the outcome of these mediated activities upon students' local activities within the excerpt and in subsequent interactions. Finally, when a link of theoretical interest between specific mediators and outcomes was found, we examined the rest of the corpus of data for both confirming and disconfirming excerpts. Confirming evidence takes the form of both similar outcomes, and those situations in which a different outcome was remarked by the participants as out of the ordinary. For example, if students were critiqued by their peers for not following what we as analysts had identified as a norm, we took this as evidence that the participants in the classroom also saw this as a norm (Cobb, Stephan, McClain, & Gravemeijer, 2001).

Analysis and Findings

Our analyses converged upon two trends of interest. First, we identified that in both classrooms there was in fact a convergence upon a standard representational feature set. Second, the inclusion and role of individual acts of creativity were different in the two contexts. However, a closer look at the data reveals that despite these trends, the classroom practices in which student engaged were quite different in terms of both the mediators and the negotiations that appeared to guide their activities.

Convergence upon a standard representational feature set

The first similarity between the two classrooms was that there was a noticeable convergence toward a normative representation. In the inventing mapping classroom this was an expected outcome as the teacher's expressed goal was to lead the students to all create a representation similar to conventional topographical maps. In contrast, the students in the representing pollination classroom rarely discussed their representations with the entire class, and were encouraged to make their own representational choices. However, because the teacher consistently promoted a specific list of features to be included, and because students saw the representations of other students working within their groups and reminded each other of this teacher's list, the end result was that students' representations did in fact converge upon a set of similar details.

Convergence When Creating Shared Representations: The case of mapping

In the case of mapping, the convergence was encouraged by the fact that the students first agreed upon a common problem to be solved before they began to work towards a specific solution. The teacher also played a major role in mediating these conversations; in some cases constraining the task, at other times asking crucial questions about the representations. For example, to get the students to "discover" that height was a problem the teacher showed the class a student's map on which a rectangle was labeled "skyscraper." This could be seen as invoking a critical part of the students' shared history to push the conversation in the direction that she thought would be productive. Other important mediators included the use of gesture to animate their representations, and the use of a shared display where different strategies were compared.

A second way convergence was encouraged in the mapping case was in the importance placed on public, whole class discussions. Our analyses revealed that most of the consequential negotiations seemed to take place during whole-class discussions. While the content of the discussions were frequently raised by students it was the teacher who was mediating and scaffolding how they interacted with each other. For example, the teacher encouraged a debate between two students who had invented different ways to represent height by revoicing certain ideas—elaborating important points they made so that they were clear to the whole class—and by positioning the argument not as a competition between the two representations but as an opportunity to work together to refine the representations so that they overcame the weaknesses that their classmates were identifying. In this way, the teacher facilitated a series of representational practices in which the students negotiated different aspects of the final shared representation collaboratively, reaching consensus on both the representational problems to be solved, and the preferred solution.

Convergence When Creating Unique Representations: The case of pollination

In contrast to the mapping classroom, the students in the pollination classroom did not collectively develop the problem to solve; they were assigned the task of representing pollination by the teacher in whole-class discussions. The specific features that needed to be included in the students' representations were frequently

discussed with the whole class while representational tasks were assigned. However, it was the ways in which students were reminded of these details and negotiated the relevance of these contributions while creating their representations that appeared to have the most impact upon the students' ongoing representational activities. Reminders took one of three forms: the teacher reminded the student of a feature that was missing from their representation, the students reminded each other of important features, and students' overheard reminders which were not directed at them.

Teacher reminders were often couched in terms that linked the representation to the process that was being represented. For example, questions such as "If we don't have a pistil can we have pollination?" appeared to highlight the link between pollination and the need for fidelity between the representation and the process. We argue that this helped develop for students an important practice of evaluating the representations of pollination with respect to their ability to describe the process as it occurs. This was also evident in the interviews when students were asked to critique a representation and often noted that the representation did not make sense because it did not depict pollination accurately. In this way, it appears that the practice of linking the representational choices to the referent ultimately led students to appropriate understanding of the features of flowers as more than just a list of necessary items.

Students also reminded each other of the representational requirements as they created their representations. These reminders often invoked the teacher as the source of the comment, and therefore the authority behind it. We see this as an important opportunity for students to practice critiquing and evaluating each others' representations based upon a series of norms that were established within the classroom for how the representations should look. We also saw multiple instances where a student demonstrated that they overheard a question or comment by moving to answer the question themselves, or contributing to the comment. Therefore, while we cannot make causal claims from this data, it appears that the students were creating their representations in a rich environment in which they were constantly reminded and overhearing ideas about what needed to be represented and how it could be done.

Implications of the Different Sources of Convergence

A major difference between these two studies may lie in the fact that in the mapping case, students were attempting to solve a shared problem that they first had agreed upon. In contrast, in the pollination case, students were instead attempting to satisfy teacher's requirements which implicitly included the problem of *how* to show pollination, but which may have been understood in different ways by different students. However, during the interviews, the students often identified the details that showed pollination occurring in the representation as important. Therefore, in both cases students appeared to have engaged in, and learned about the practice of designing and creating a representation that effectively communicates the object that it is designed to represent. However, in the mapping classroom, solutions to this problem had to be negotiated collectively as students vied for the best solution and students gained experience in a form of social practice that involved proposing and evaluating specific solutions. The students in the pollination classroom primarily had to identify the specific solutions that fulfilled a given set of constraints and learned to participate in a social practice where the peers and the teachers helped each other find a solution by monitoring how their own and others met or violated these constraints.

One additional implication resulting from this difference in how the problem to be solved was defined—collectively or individually—is the degree to which members in the given classroom had access to a shared history of the problem definition and solution. In the mapping classroom, this shared history became an important resource in helping to coordinate the collective activity as the members of the community referenced their previous representational challenges while developing a solution. In contrast, the students in the pollination classroom had privileged access to their own history with a given representation in that their peers and the teacher were not present for many of the ongoing negotiations and resulting decisions. The students rarely revealed this history unless specifically asked to, and so the motivation behind many of their representational choices often remained somewhat opaque to their peers and the teacher.

Agency within students' representational activities

As mentioned above, the students in the representing pollination classroom were encouraged in creating individual representations according to their personal preferences, and it was therefore not a surprise to find a great deal of variability in their representations. However, even after agreeing upon a convention for their shared

representational form, the students in the mapping classroom also showed a great deal of individual innovation in their final maps.

Agency When Creating Shared Representations: The case of mapping

In the mapping case, an important step was the development of a set of standards which were then applied in refining the shared representation. Specifically, the students were engaged in debating the value of particular representational forms, but to do this they had to develop the criteria which they were using to compare them—does the system show height? Can it be used to compare heights? Does it distort or lose other types of information to show height? Individual agency was most visible in these discussions in the fact that particular representations invented and promoted by individuals were the vehicle by which these criteria were developed. For example, one invented representation was to add shadows to objects on the map to show that they were tall. The invention of shadows was critiqued on the grounds that it did not show exactly how tall an object was. Therefore, it was the invention of a representation by an individual that led to a collective criteria by which all representations were judged from then on.

Agency When Creating Unique Representations: The case of pollination

In contrast, in the pollination case, individual agency and personal preference were important ideas encouraged by the teacher, and leveraged by the students in their separate representational activities. Early in the study, students' personal preferences often filled the gaps in their content knowledge when making representational choices. For example, it was not necessary to use a specific pollinator, and therefore students created whatever pollinator they preferred. However, the teacher slowly added representational norms. Near the end of the study students were required to depict a pollinator that was a good fit for the type of flower that they selected. This appeared to engender a rich set of negotiations in which students chose to balance their personal preferences with the norms that were established, and frequently "anchored" their norm-satisfying choices in a personal choice. For example, students might choose to represent a hummingbird because it was their favorite pollinator (as reported during the interviews). However, they then chose flowers which matched the hummingbird (those where a long beak is necessary to reach the nectar). Over the course of the study, the interview results show a marked increase in students citing details (such as the relationship between a pollinator and the flowers it can pollinate) as important factors in their representational choices. Students also cited personal preferences less often when describing how they made their choices. This trend appears to have paralleled an ongoing transformation in students' representational practices. Initially, students only needed to attend to a limited set of details to be represented, relying upon their peers and the teacher for reminders as needed, and their own personal preferences to fill in the gaps. Over time, however, as students appeared to appropriate this list of the details, the teacher added additional important details for the students to take into account in their representations. In this way personal preference played an important role in facilitating students' invention of representations before they knew of all of the details that they needed to include.

The lack of focus on a shared representational form also lead many individual acts of creativity to stay local in that only a handful of other students saw each particular student's choices, and there was no requirement that they follow those innovations. In fact, we argue that students were required, therefore, to actively negotiate, or choose which suggestions (either implicit or explicit) to implement in their representations on their own (as opposed to being facilitated by the teacher), which is an important representational practice.

Implications of the different roles of agency

In the mapping case, individual agency was leveraged as individual's representations were negotiated and then sometimes adopted as the normative representation by the collective. The practice of presenting and then defending or critiquing one's individual representation in the public space was important, and developed. Individual agency in the pollination case played a very different role. Practices centered on the creation of representations instead of debate. In their design decisions students made use of personal preferences to fill in the gaps in their understanding as they engaged in the process of reconciling their choices with the representational norms established by the teacher. Individual agency was therefore central to the two different contexts, but for very different reasons. In the one case, students developed and exercised the ability to contribute *to* the shared representation, while in the

other, students work within representational norms established *for* the classroom by an external force (i.e., the teacher) was facilitated by their individual acts of agency and preference.

Discussion

A number of important differences can be highlighted between these two contexts in which students invented representations by examining both the negotiations and mediators which played a central role in students ongoing activities. In the case of creating a shared representation the key negotiations occurred publicly, between students (though facilitated by the teacher). This leveraged students' argumentation practices as they proposed and evaluated various solutions to the representational problems which had been collectively established as important, as well as giving importance to the representational form. In contrast, the key negotiations in the case of creating unique representations were those in which the student locally balanced their own personal preferences with the task contingencies and their peers' influence. While this occasionally occurred in public, it was still the author of the representation who ultimately weighed the available options and competing constraints and made a final choice about how to proceed based on her own preferences and current level of understanding, giving primary importance to the content being studied, as opposed to the specific representational form.

In both contexts students' activities were also mediated by a number of factors including a series of developing classroom norms, their peers, and the local physical materials. However, even similar mediators played a very different role in students' activities, particularly given the way they were involved in ongoing influential negotiations. For example, in the case of creating shared representations, students' peers were central mediators who provided important critiques, or served as an audience to be convinced of the power of a particular representational solution. In contrast, the peers in the classroom oriented towards creating unique representations appeared to play a role of providing suggestions and reminding each other of classroom norms (another important mediator) as students struggled to represent their current understanding of the content.

This analysis reveals the importance of taking a closer look at the mechanisms through which participants within a given classroom invent different kinds of representations. In addition to the impact that these activities have upon students' math or science activities, there is a reciprocal relationship between students' representational practices and activities involving invented representations. Specifically, the organization of the invention activity may leverage or require a specific set of practices as well as leading towards students' development of similar practices. It may also privilege either the representational form being developed, or the content being represented as a topic for ongoing discussion, and possible learning. The NeRM framework proved to be an effective way of identifying these subtle differences between representational activities. Attention to these details can help instructional designers to carefully select activities that build upon students existing representational practices while also supporting researchers as they attempt to analyze students' representational activities, and the way in which they may lead to their learning of new content.

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