MIND, CULTURE, AND ACTIVITY, *11*(4), 279–300

Generalizing in Interaction: Middle School Mathematics Students Making Mathematical Generalizations in a Population-Modeling Project

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Generalizing or making claims that extend beyond particular situations is a central mathematical practice and a focus of classroom mathematics instruction. This study examines how aspects of generality are produced through the situated activities of a group of middle school mathematics students working on an 8-week population-modeling project. The project involved creating and analyzing mathematical models of population growth. Two classroom episodes are presented that focus on students' activities across curricular tasks in which they discuss the category of sensible models of population growth and describe a pattern of guppy population growth in a natural environment. Participation frameworks introduced in the context of the episodes describe how students compare situations to determine if they belong to the same general category and predict and justify the behavior of modeled phenomena. The analysis suggests that mathematical generalizing is the outcome of processes distributed across students, tasks, embodied activity, and modeling tools.

"They're always growing at the fifty-seven percent birth rate but since there's more guppies it's always like—it's always like changing the population … it's gonna be a larger amount of guppies born every, every season."

—Max, an eighth grade mathematics student, explaining why a linear model is not a sensible model of population growth

In the above statement, Max describes why the number of guppies born "every" season would "always" increase as the size of the population increases. In essence, he is describing a general pattern of exponential growth. Focusing on the generalization that was made in this particular moment is to only look at a final product; it does not help us understand the process through which general claims such as this one are made. The aim of this article is to examine how aspects of generality are produced through the talk and activities of one group of eighth grade mathematics students as they

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worked on an extended population-modeling unit called Guppies (Middle School Mathematics Through Applications Project, 1997).

Being able to see and describe general patterns is a central mathematical practice and it is widely agreed that students should learn to generalize from pre-K to the 12th grade (National Council of Teachers of Mathematics, 2000). Seeing mathematical patterns is not, however, a transparent activity; it requires figuring out what is important to pay attention to and what to ignore in and across situations and how to use mathematical forms, such as graphs, to identify relevant mathematical phenomena (Goodwin, 1994; Latour, 1987; Verran, 2001). Because generalizing is a central mathematical practice, documenting how students learn to describe how something always behaves will help us understand how students enter into the specialized disciplinary discourse of mathematics.

The article begins with a description of the conceptual framework that informs this study. This is followed by an overview of cognitive approaches to studying generalizing and a more detailed discussion of the situated approach used in this analysis. A description of the classroom setting, study participants, and the curriculum unit will then be presented. In this section, readers will be introduced to the focal students through an analysis of their typical ways of interacting with one another and engaging with curricular activities. The discourse analytic methods used to identify how the students participated in processes of generalizing are then explained and illustrated.

The focus of the article is an analysis of two episodes from the beginning and end of the 8-week Guppies unit. The episodes show how the students participated in generalizing and developed general understandings of the behavior of populations. Two participation frameworks are presented in the context of the episodes that detail how the students *link* situations together so they can compare them and *conjecture* about the future and past behaviors of real-world phenomena. The article concludes with suggestions for supporting mathematical generalizing in classrooms and further questions for studying generalizing.

CONCEPTUAL FRAMEWORK

A situated approach to learning is based on the assumption that people learn through gradual participation in the socially and culturally organized practices of a community (Lave & Wenger, 1991). Rather than viewing mathematical patterns as directly perceptible, a situated perspective recognizes that mathematical ways of seeing and knowing are socially, culturally, and historically constructed (Lave, 1988; for a philosophical treatment of the problem of induction and the development of generalizations see Quine, 1995). As such, a situated approach is useful for understanding the processes of learning mathematics in classrooms particularly in illuminating how students and teachers develop shared ways of talking, acting, and using tools to engage in mathematical activities (Greeno & The Middle School Mathematics Through Applications Project Group, 1998). This perspective draws attention to how classroom conversations and activities are organized so that students have opportunities to engage in mathematics in the classroom.

Examining the *participation frameworks* or sets of participant roles that open up when an utterance is spoken enable an analysis of how students gain access to mathematical discourse and practices (Goffman, 1981; Goodwin & Heritage, 1990; O'Connor & Michaels, 1996). These roles shape how students are able to engage with the topics being discussed, participate in classroom instructional activities, and thereby learn. In addition to the importance of talk, research on mathematical activities in and out of school has drawn attention to how the organization of the tasks in which one uses mathematics, the physical materials available in the setting, and the coordination of talk with gesture shape participation in mathematical activities (Hall & Rubin, 1998; Lave, 1988; Saxe, 1991; Scribner, 1986; Sfard & Kieran, 2001). In this study, the analysis of participation frameworks focuses on how students use talk, embodied activity such as gesturing, and inscriptions including graphs and diagrams to engage in mathematical generalizing.

COGNITIVE AND SITUATED APPROACHES TO STUDYING MATHEMATICAL GENERALIZING

The power of mathematics derives from its abstraction and generality. Cognitive psychologists view generality as the development of decontextualized knowledge that can be applied in any situation (Anderson, Reder, & Simon, 1997). Learning, they argue, is not tied to specific contexts but depends on developing mental representations that correspond to an external reality. Generalizations are the product of accurate mental representations and from this perspective generalizing is an individual cognitive activity performed to recognize and acquire objective categories. In assuming that objective categories exist outside of the activities of people, traditional cognitive theories do not account for the intentional and generative processes through which people make their own categories and representations to make sense of the world. Furthermore, from this perspective, if a mathematics curriculum is well designed, students should be able to acquire the information it presents (e.g., mathematical patterns) without any difficulty. If the information is not acquired adequately, the only explanation provided by a traditional cognitive approach is that either the students or the teacher are not functioning as they should.

Building on Piaget's approach to intellectual development, Dienes outlined a theory of mathematics learning through which one begins with concrete, hands-on materials (e.g., Dienes' Blocks) and then abstracts structural features of situations (Dienes, 1960). Under this view, abstraction requires a move away from concrete situations, which leads to the recognition of general patterns. Dienes' analysis emphasizes the importance of reflecting on situations; however, it downplays the roles of cultural artifacts and settings in shaping the processes through which people identify and develop generalizations (Seeger, 1998).

From a situated or practice-based perspective, abstracting is conceptualized not as "moving away from" situations, but as a product of local practices. Such a view attends to how social interactions, tools, personal history, and the environment shape the creation and recognition of similarity across situations (Dreyfus, Hershkowitz, & Schwarz, 2001; Greeno, 1997; Noss & Hoyles, 1996). Generalizing or making claims that can be applied to a variety of objects or situations is likewise understood as a social practice rooted in people's activities and discourse (Davydov, 1990; Latour, 1987; Lerman, 2000).

Studies of classroom mathematical discourse have emphasized the importance of whole-class and public discussions in helping students to make claims that span multiple cases. Discursive strategies used by teachers to support students' efforts to generalize include the establishment of norms of classroom interaction that encourage students to explain and justify their mathematical claims, revoicing student contributions to draw out similarities across findings, and collective reflection on the activities of multiple students to generalize across specific cases (Cobb, Boufi, McKlain, & Whitenack, 1997; Lehrer, Strom, & Confrey, 2003; O'Connor & Michaels, 1996).

Hall and Rubin (1998) described how students' mathematical accounts became more general or broadly applicable as they moved from local to more public classroom settings. Their analysis draws attention to the changing interactional demands of classroom settings and the need to consider the purposes for which an account is given, to whom it is directed, and the kinds of representational resources that are available and acceptable for use in a particular setting.

Studies of technoscientific practice have also had a significant influence on analyses of mathematical generalizing in classrooms. In particular, Latour's (1987) analysis of the construction of general claims in professional scientific practice emphasizes that generalizations are not objective, but are shaped by who states them, how they are connected to other claims, and the use of inscriptions to make claims that span multiple cases. Inscriptions such as graphs and diagrams can be used to foreground and background aspects of situations, which can be manipulated, recombined, and used to assert a particular view of the world and persuade others to take on this view (Greeno & Hall, 1997; Latour, 1990; Roth & McGinn, 1998). For example, a table of guppy population growth can emphasize relationships between time, births, and deaths, which are not directly accessible to a person looking at live guppies in a pond (see Figure 1).

Inscriptions such as this can support generalizing because they allow one to represent and draw together information about situations that extend across time and space (Latour, 1990). Using this table, for example, one could generalize about the growth of a guppy population over 3 years. Furthermore, through the development and enactment of mathematical narratives or stories about the behavior of mathematical phenomena and situations, it is possible to imagine, explore, and share

Time	Guppies	GuppiesBirths
Winter 1990	10	20
Spring 1990	30	20
Summer 1990	50	20
Autumn 1990	70	20
Winter 1991	90	20
Spring 1991	110	20
Summer 1991	130	20
Autumn 1991	150	20
Winter 1992		
Spring 1992		
Summer 1992		
Autumn 1992		
Start of Winter 1993		

FIGURE 1 A table representing guppy population growth over 3 years.

analyses of past and future situations (John, Luporini, & Lyon, 1997; Nemirovsky, 1996; Ochs, Jacoby, & Gonzalez, 1994). Shifting across time and space to describe how something typically behaves is, as will be shown in this analysis, an important resource for generalizing.

SETTING AND PARTICIPANTS

The data presented in this article were collected as part of a larger ethnographic research project that compared the development and organization of mathematical practices across school and work settings in which design was a leading activity (Hall, 1999). This study focuses on a group of four students working on a population-modeling project in an 8th-grade mathematics classroom in Northern California. The school served a socioeconomically and ethnically diverse student population. Thirty-eight percent of the students at the school received free or reduced-priced lunches.

As part of her participation in the research project, the classroom teacher Ms. Alessi[1] taught two extended design units during the 1996–1997 school year. The first focused on architectural design and the second, discussed in this analysis, focused on population modeling. Prior to and throughout the school year, Ms. Alessi participated in after-class debriefing sessions and weekly research project meetings in which members of the research team discussed curricular activities and assessments, redesigned activities, and reviewed and discussed videotaped classroom interactions.

The focal student group was selected because they were filmed during the first design unit and we wanted to document their activities over the course of the two units.[2] They were initially selected because the teacher thought they would be most likely to participate in the activities of the project. This approach allowed us to study what engagement in these project-based curriculum units might look like. The members of the group included four boys: Gento, Patrick, Andre, and Max. Gento, Patrick, and Andre[3] were group mates during the first unit. Max, a member of another focal group filmed during the first unit, joined this group for the second unit. Based on classroom observations and a content-level analysis of all groups' participation in a design review in which students presented their guppy population models and tank designs to visiting biologists, this group was found to be representative of the class in terms of the culminating products they created as part of the unit. Specifically, the focal group's guppy population model and tank design were comparable to those of other groups in terms of their attention to the task constraints, level of detail in the population model, and level of sophistication in discussing their models with visiting biologists.

GUPPIES UNIT

The Guppies unit is organized around simulated real-world problems that provide opportunities for students to engage in standards-based math topics (National Council of Teachers of Mathematics,

[1]All proper names are pseudonyms.

[2]A second focal group was also filmed during the Guppies unit. Filming in the classroom was shared by two researchers who alternated between filming the focal groups and whole-class discussions and presentations. As a result, I have documentation of the focal group's activities as well as other students' activities, which were used to make broad comparisons.

[3]The fourth member of the group transferred schools before the beginning of the second curriculum unit.

2000). The premise of the unit is that students have been hired as biological consultants who need to provide advice about how to maintain a population of guppies that have been rescued from a polluted stream in Venezuela. The students-as-consultants are asked to model the life cycle of the population for 2 years and design a tank that can house the predicted number of guppies. By providing a meaningful context in which students use mathematical concepts and methods to create and analyze models of guppy population growth, Guppies can become an effective environment for learning about linear and exponential models, birth rates and death rates, and functional relationships between multiple variables.

There were four phases of the project as enacted in Ms. Alessi's classroom. First, students conducted research on guppies and populations, which informed their construction of population models using modeling software called Habitech©. The second phase involved the analysis and comparison of different models of guppy population growth. The third phase required designing a tank with enough top surface area and volume to house the guppies in a healthy environment. During this phase, the students presented their models to visiting biologists who reviewed and critiqued their models. The final phase of the project involved working on a design challenge created by the research team in which students modeled how a guppy population would grow in a polluted pond environment (the pollution scenario).

The Focal Students: Managing Relationships and Participation in Mathematical Activities

The relationships between the members of the student group shaped the trajectories of the mathematical activities and thereby the contexts in which generalizing was embedded. How the focal students typically participated in their group was revealed through ethnographic analysis of the focal students' interactions with one another during the two curriculum units used in Ms. Alessi's classroom (see John, 2001 for an analysis of the students' activities during both curriculum units).

During the first unit, Patrick and Gento established themselves as leaders of the group's mathematical activities. A number of factors contributed to and supported their leadership positions including that, according to their performances on classroom assignments, they were the strongest academically in the group. Additionally, Gento was quite capable of and interested in mathematical problem solving and was more comfortable and familiar with using computers than his group mates. However, he did not turn in his work as often as the teacher required. On the other hand, Patrick was very aware of and oriented toward the official demands of the classroom such as due dates and the requirements of an assignment. His attention to task requirements allowed him to assert authority in the group regarding what needed to be done and when (Gento referred to him fondly as "supervisor"). Gento's and Patrick's approaches to schoolwork complemented each other and they developed a reliance on one another.

The actions of the other members of the group, one who was minimally interested in academic activities and the other (Andre) who struggled more with the mathematical aspects of the tasks, ratified Patrick's and Gento's leadership positions in the group. Furthermore, Andre's absences (during the first and second curriculum units) on days when the group made decisions that affected the subsequent design of their models and presentations to the class about their analyses served to fix his peripheral position in the group.

Max's arrival during the Guppies unit shifted the dynamics of the group. Max was a close friend of Patrick's and they often talked about mutual friends and weekend plans while working. Gento and Patrick to some extent viewed Max as not very serious about schoolwork because he would often make jokes and as Gento described, "goof off" (Fieldnotes 5/13/97). In regard to the official work of the group, Max struggled to take part in what had previously been the exclusive territory of Gento and Patrick. In the following excerpt, Max complains because Patrick has decided that he and Gento should represent the group in a presentation to the class.[4]

5/15/97

1 Patrick: Who's gonna go up there (to present at the front of the room)?
2 Andre: I don't know.
3 Patrick: I'll go. Me and Gento.
4 Andre: Okay.
5 Gento: Yup.

While Andre readily agrees to this division of labor, Max questions why he is being excluded.

1 Max: Are you saying I wouldn't go up?
2 Patrick: No, if you want to go, okay, so?
3 Max: …That's what I'm saying. I understand it. I know that material.

While Patrick and Gento would not consult Max regarding mathematical activities, Patrick and Max would not include Gento in conversations about more unofficial topics (e.g., about friends). These tensions shaped how the group made decisions regarding whose contributions the group would consider seriously, what problems were worth pursuing, and when an answer was good enough. These issues were significant because they affected both when and how mathematics-relevant moments emerged out of the group's activities (McDermott & Webber, 1998).

STUDYING GENERALIZING IN CLASSROOM INTERACTION

Analytic Methods

This study used methods from discourse analysis to study both verbal and nonverbal forms of interaction (Erickson, 1992; Goodwin & Heritage, 1990). Attention was paid to the participation frameworks that emerged as the classroom participants attempted to generalize about real and/or hypothetical events. The stances or "footings" participants took toward an utterance or other action provided a way to study how they oriented to and evaluated a situation (Goffman, 1981). Evidence of footing included the content of what was said, the relation of what was said to the larger context of talk, and the participants' tone of voice and body language. Documenting how classroom partic-

[4](…) Parentheses indicates transcriber comments, (#) actions are indicated with a number inside a parentheses in a turn at talk and action descriptions are provided in the right-hand column, contiguous utterances are indicated with equal signs, and :: elongated syllables are indicated with double colons.

ipants used and coordinated talk, gesture, and inscriptions to assume or position others to take on a particular point of view was valuable for understanding the development of general perspectives (Hall & Rubin, 1998; Latour, 1987).

Conversation analysis was an important lens for understanding how classroom participants used talk as a resource for generalizing (Sacks, Schegloff, & Jefferson, 1974). A conversation consists of a sequence of turns and conversation analysis focuses on the level of turn-taking organization in an interaction. A central concept in this tradition is the “adjacency pair,” which refers to the fact that when a participant in an interaction makes an utterance, this utterance affects the subsequent utterance in that it raises expectations regarding its content. For example, in a question–answer sequence, after one person asks a question, the subsequent utterance will most likely be an answer or be heard as an answer to the question. Schegloff (1976) described the second utterance as being “conditionally relevant.” Because utterances set up expectations about what will likely follow, it was possible to examine the order of conversational sequences and draw conclusions based on those occasions when expectations were not met.

Developing Analytic Categories

The following is a description of the process of developing the category of “linking,” one of the ways in which classroom participants used talk and interaction to generalize. For the sake of clarity, the iterative process used to develop analytic categories will be described in a more linear fashion. Analysis began with the creation of content logs of classroom videotapes documenting the activities of the focal student group during the Guppies unit. Content logs included descriptions of what happened in the classroom and short analytic notes discussing and comparing events at a more theoretical level (Strauss, 1987; Jordan & Henderson, 1995). Transcripts, which included reference to linguistic and paralinguistic features of speech such as intonation and activities with material objects, facilitated this analysis and provided a way to examine the processes of generalizing in detail.

After identifying and examining all instances in which students either attempted to generalize or did generalize, preliminary codes were developed to describe classroom participants’ activities. On a number of occasions, the teacher and students compared one kind of thing to something else to generalize about their behavior or characteristics. Consider the following example:

06/03/97

Max:	It’s (a pattern of population growth) like a person’s body weight. When you get to a certain weight (Patrick throws his head back with laughter), your weight (1) fluctuates, but it stays around the same area, going down (2) and up, (3) down and up…	(1) arms sway in a large range (2) arms sway in a smaller range (3) arms sway quickly back and forth

In this excerpt, Max compares another student’s description of how a population might behave when it reaches the carrying capacity (or upper limit) of its environment to fluctuations in body weight, something with which he is more familiar. Moving his arms in coordination with his description of the sizes of the fluctuations, he suggests the similarity to members of his group to better understand the phenomenon they have just discovered.

This phenomenon was preliminarily coded as "linking" because it involved making links or connections between two or more situations, which seemed to support making general claims. In this case, Max drew a comparison to what he thought was a similar situation to help his group mates predict how a population would behave as it reached the carrying capacity of its environment.

This working code was then used to identify more episodes in which the students and teacher would be likely to discuss or show how one thing was like another. In the language of grounded theory, this process of locating instances is called theoretical sampling (Glaser & Strauss, 1967). Using the intended curriculum as a guide, curricular activities were identified that encouraged students to make connections between curricular activities. Throughout this process, analytic memos were written to describe the interactional roles and conditions under which classroom participants engaged in an activity. For the purpose of investigating the development of generalizations it was necessary to consider the interactions that preceded and followed a linking episode. How was the comparison initiated and elaborated? How did the person(s) to whom the comparison was proposed respond? What happened when participants agreed or disagreed about a proposed similarity? Access to the longitudinal record of the students' activities was important in this regard.

After identifying possible cases of linking, their sequential organization was described using transcripts that visually represented the patterned ways in which participants used and coordinated talk, gesture, and material resources (Goodwin & Heritage, 1990). Comparison of multiple episodes of linking led to a description of the typical organization of a linking sequence, its common variations, and the exclusion of certain cases. Following this same general method, the activity of conjecturing and its relation to mathematical generalizing was identified and described.

GENERALIZING IN INTERACTION

In this section, two episodes from the Guppies unit are presented that describe how the focal students engaged in linking and conjecturing to develop general understandings of guppy population growth over the course of the unit. In the first, from the middle of the unit, the students engage in linking as they discuss what it means for a model to be a "sensible" model of guppy population growth. In the second episode, from the end of the unit, the students use their understandings of sensible or realistic models of growth to conjecture about what would happen to a guppy population when it reaches the carrying capacity of its environment.

Episode 1. "What Does Sensible Mean?": Linking to Describe General Patterns

Linking is the process of creating and applying classification systems. It is important for generalizing because it involves determining whether two or more situations are the same and, if so, whether they can be treated in the same way. The question addressed in a linking sequence is, "Is this one of those?" Linking consists of three steps through which participants (a) compare two or more situations, (b) orient one another to relevant similarities and differences between the situations, and (c) evaluate the comparison.

This episode takes place in the middle of the Guppies unit. The students have researched guppy population growth, created their own guppy population model on the computer, and constructed graphs of how the population will grow over 2 years.

The students are working on an assignment that asks them to analyze different models of guppy population growth using both tables and graphs. On the assignment sheet is a table of data representing a linear model of population growth in which the population grows the same amount every year (see Figure 1). Students are asked to complete the table by continuing the pattern and then to create a graph of the data. The focus of the group's conversation is a question on the assignment sheet that asks whether or not the linear model in which the guppy population grows the same amount every season is "sensible."

Comparing

Linking begins with a comparison. After completing the table and graphing the data, Patrick turns to Gento who has already finished the first part of the assignment and asks:

05/09/97

1 Patrick: What does sensible mean? I don't get this. I don't get "b" (the second part of the question)
2 Gento: Sensible, it's like, does it make sense heh.
3 Patrick: Yes.
4 Gento: It DOES make sense?
5 Patrick: Yes.
6 Gento: What did our guppies graph look like?

In this excerpt, Gento sets up a comparison between the linear model and a known sensible model of population growth, the exponential model of guppy population that the group has created.

Orienting

The second step of a linking sequence involves orienting to similarities and/or differences between situations. In the following orienting sequence, Gento uses talk and gesture to show Patrick how the two graphs differ. He leans over Patrick's assignment sheet and says:

7	Gento:	It didn't look like a straight line. It went up like that (1) because there's more guppies and more repro—repro—reproduction.	(1) traces a curved line over Patrick's linear graph

Gento traces a curved line representing the growth of the group's guppy model, a model where the population grows exponentially, over the straight line of Patrick's linear graph (see Figure 2).

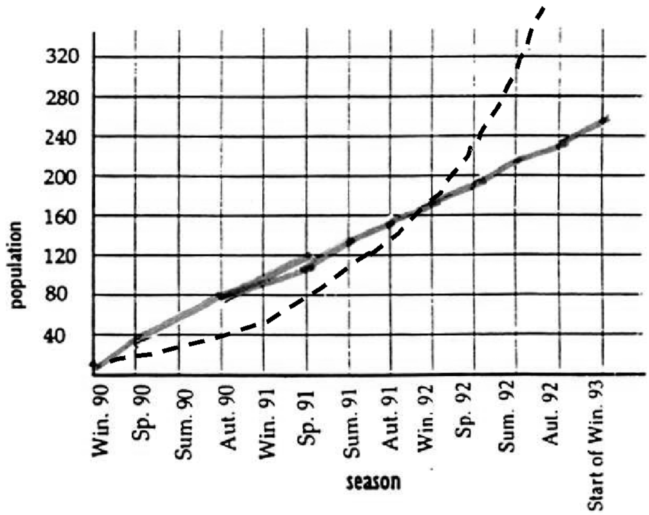


FIGURE 2 Patrick's graph of a linear model of guppy population growth with the curved (dashed) line that Gento outlined over it.

By drawing on their shared history and using gesture to recollect the group's graph in this exchange, Gento creates a situation in which he and Patrick can compare the two graphs.

Evaluating

The linking sequence concludes with a joint evaluation of the comparison between the two situations. Patrick decides, possibly because he doesn't completely understand the distinction Gento is making between the two models that the linear model is "different" from the group's population model and starts writing this on his assignment sheet. Max who has been privy to the exchange, but who has not yet worked on this part of the assignment chimes in to support Patrick's position and the following conversation ensues:

12 Patrick: This is different.
13 Max: This is a different model. We're working with a different model. We're feeling like working with a different model. It's a different model.
14 Gento: Well it doesn't MAKE SENSE.
15 Max: It's a model and it's different. Just let it go.
16 Gento: DOES IT MAKE SENSE OR NOT THOUGH?

The conversation about whether or not the model is "sensible" ends at this point. Patrick has found an answer that he thinks is good enough even though Gento continues to insist that the models are not just different but that the linear model does not make sense.

Why Linking is Important for Mathematical Generalizing

In this example, the students were attempting to generalize about what constitutes the category "sensible models of population growth." The activity of linking is important for understanding generalizing for two reasons. First, linking draws attention to the ambiguity involved in comparing across situations and how participants negotiate this ambiguity to create shared or partially shared understandings of situations. That the students do not come to a shared understanding of what constitutes a "sensible" population model highlights the work that is involved in coming to see two situations as being the same or belonging to the same general category. Second, linking is important because it describes what people do with each other, with inscriptions, and with their bodies to investigate and compare mathematical situations. In this regard, the assignment that the students worked on provided an important support for the activity of linking. Comparing across different ways of representing models of growth supported the students in identifying the relevant features of sensible models of growth.

As shown in the quote that opened this article, Max was able to explain why the linear model is not a sensible model of growth ("since there's more guppies it's always like—it's always like changing the population … it's gonna be a larger amount of guppies born every, every season"). He made this statement during a presentation to the class following the group's work on the assignment. While tracing the development of his understanding is beyond the scope of this analysis, Max's generalization about how the guppy population would grow exponentially points to a further dimension of the social organization of generalizing, attention to students' purposes for generalizing. Presenting and explaining an analysis to the class provided more of an impetus for Max to develop his analysis of the linear model than did completing a worksheet. When he needed to address the same question posed by the worksheet, he was oriented toward "getting an answer" rather than discussing the problem in depth. This was revealed in his insistence that they "just let it (the question and their answer) go."

As described in the next section, the distinction between what is a "different" versus a "sensible" model of population growth shapes the students' later work in the project and their developing understandings of how populations behave.

Episode 2. Dealing with "Overpopulation": Conjecturing to Describe and Explain General Patterns

Conjecturing is the process of describing and explaining the behavior of objects and situations. Conjecturing is important for generalizing because it allows one to answer the question, "What would happen if?" A conjecturing sequence consists of three main steps: (a) discussing a situation that involves making a prediction, (b) describing a general pattern, and (c) explaining this pattern.

This episode takes place at the end of the Guppies unit. In it, the students are working on an assignment called the pollution scenario, which was an extension problem designed by the Math-at-Work Project. The problem extends the fictive premise of Guppies and picks up after the guppy population the students have been modeling throughout the unit is returned to their natural habitat, a stream in Venezuela. Students are informed that the guppies have been thriving in the stream for a year, but that an unspecified amount of pollutant has recently entered the stream. They are now asked to predict the effects of the pollutant on the population over the next 3 years.

This problem asks the students to transfer their understandings of guppy population growth and population modeling to a new, but related, situation.

Students were given a diagram of a stream and a guppy pond (see Figure 3). The diagram is a mathematized representation that depicts the pond as a “tank-like” geometric form with labeled dimensions for its length, width, and height (Lynch, 1990). The diagram was designed to resemble the tanks students constructed earlier in the unit to encourage them to refer to the procedure they used to find the carrying capacity of their fish tanks to find the carrying capacity of the pond. In addition to building on prior activities, the pollution scenario provided students with novel modeling opportunities such as describing the guppy life cycle in a natural environment and modeling the effects of an external factor (i.e., pollution) over time.

The focal students began their work on the problem by determining the carrying capacity of the guppy pond. Gento calculated the number of guppies that could live in the pond by referring to the group’s research on guppies and the procedure they used earlier in the unit to design a guppy tank. He determined how many guppies the pond can support (its carrying capacity) by calculating the top surface area of the guppy pond (400cm × 500cm) and dividing it by the amount of top surface area that a guppy requires to get enough oxygen to live (30cm). He found that the maximum number of guppies that could live healthily in the pond is 6,666 guppies.

Keeping this number in mind, Gento and Patrick led the group in building a step-wise population model to investigate the effects of the pollutant on the guppy population. Specifically, they built four population models with different birth and death rates for each year of the model and connected the four models (“steps”) sequentially so the ending population value of one model would be the starting value of the next model. After running through all the years of the model, they found that the ending number of guppies would exceed the maximum capacity of the guppy pond; the students refer to this as “overpopulation.”

Andre, Max, and Patrick each proposed ways of revising the model to Gento, who was in charge of adjusting the parameters of the model on the computer. Andre suggested adding a predator to the model to reduce the number of guppies in the pond; Max proposed “killing” off the number of guppies that exceed the capacity of the pond because he knows there cannot be more than 6,666 guppies in the pond; and Patrick suggested altering the timing of the guppy death rates in the model so more guppies will die over time. Gento follows Patrick’s proposal, but even with more guppy deaths they find that the pond is still overpopulated.

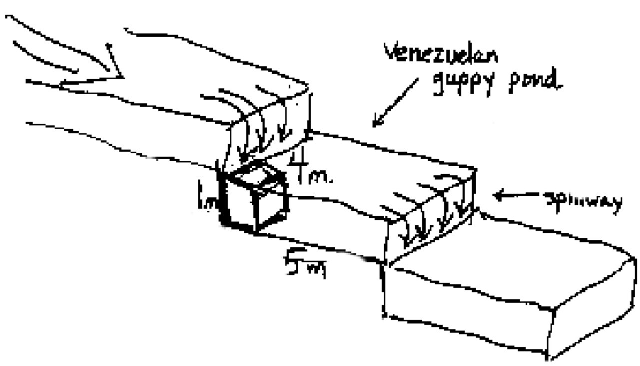


FIGURE 3 The diagram of the guppy pond given to students.

Gento suggests completely altering the group's population model so that it includes immigration and emigration, two functions available in HabiTech© with which he has experimented earlier in the unit. By setting appropriate values for the immigration and emigration functions, Gento hopes to reduce the number of guppies so they can "fit" in the pond. This approach would require creating a more complicated population model using functions on the computer that the group has never used before. It would also require reinterpreting the stream diagram as an "open" biological system in which guppies could travel in and out of the pond.

Patrick and Max argued against Gento's proposal to revise the model because, as Patrick put it, they should just "finish it and be done" and "get (their) credits" because this was the last assignment of the semester (06/03/97). Furthermore, the group has spent 2 days working on the problem and, as Max pointed out, they already have an answer, which is that the guppies will overpopulate the pond.

At this point, the students have reached a stalemate and have decided to ask the teacher for help. The following describes how the students and Ms. Alessi engage in conjecturing to imagine what will happen to the guppies over 3 years.

Discussing a Future Situation

Ms. Alessi initiates a conjecturing sequence by posing a hypothetical question that asks the students to consider what would happen to the guppy population at the critical moment in the students' model when the guppy population approaches the carrying capacity of the pond.

06/03/97

1 Ms. Alessi: Okay, so my question is what would happen to the guppy population when it reaches say six thousand, sixty-six hundred? What's happening?

Describing a General Pattern

In response to her question, the students use talk and gesture to animate narratives about what will happen when the guppy population reaches the carrying capacity of the pond. While earlier they were focused on how to model the situation using the software, the teacher's question opens up the conversation, and the students then describe what might happen. Gento proposes that the population will increase and decrease in a regular cycle and uses talk and gesture to animate what he thinks will happen to the population.

4	Gento:	It's gonna—it's gonna increase uh (1) slowly and go down (2) and go up (3)	(1) raises one hand above the other (2) lowers top hand (3) raises top hand

Drawing on a more familiar experience, Max asks whether he can "give 'em the metaphor" and then proposes that population growth is similar to fluctuations in body weight.

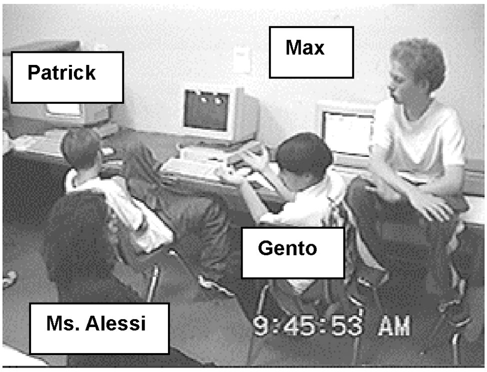
7	Max:	It's like a person's body weight. When you get to a certain weight, (Patrick throws his head back with laughter) your weight (1) fluctuates, but it stays around the same area, going down (2), and up (3) down and up=	(1) arms sway in a large range (2) arms sway in a smaller range (3) arms sway quickly back and forth
8	Patrick:	(1) (quietly to Max) No::oo.	(1) wags his finger dismissively at Max
9	Gento:	Okay.	
10	Max:	= so they're not gonna—not gonna keep growing and growing and growing.	

Max coordinates his talk and gestures to describe how once a person reaches a particular (fairly stable) weight, fluctuations are fairly small. He demonstrates this by using his arms to make smaller and smaller repeated, swaying movements around a central position representing that "certain weight" (actions 2 and 3). Max's metaphor elaborates on Gento's spare description of the growth of the population as it reaches the carrying capacity of the pond. In addition to comparing the growth of the guppy population to fluctuations in body weight, Max concludes that the guppy population will not "keep growing and growing and growing," but like body weight, it will fluctuate around a particular level. Notably, however, Patrick laughs dismissively at Max's contribution possibly because Max is not seen as mathematically competent in the group and/or because he expresses his understanding in a way that is unusual in this classroom (i.e., drawing on experiences from outside of the classroom).

Justifying

In his next turn, Gento explains why the population would follow this general pattern of growth, specifically, why it would not exceed the carrying capacity of the pond. Making reference to the group's earlier research on the habitat requirements of guppies, Gento states and shows how the top surface area of the pond would limit the number of guppies that could live in the pond. When the pond becomes too full of guppies, he explains, they would not all be able to get oxygen at the top surface area of the pond and so some would suffocate and die (see Figure 4):

13	Gento:	It'll go up and down (1) because there there'll be guppies (2) births and stuff and they would need oxygen and that would (3) that would take up oxygen and some would suffocate (4) to death and stuff like that and y—y'know too much room being y'know used and then (5) and so the population go down but then	(1) hands move alternately up and down (2) hands create a flat surface (3) hands roll upwards (4) both hands open and are lowered (5) right hand is raised then lowered



(8) some will grow and	(8) hands are raised	
(9) some die so it'll be	(9) hands are lowered	
(10) steady	(10) right hand moves up and down in a small range to show a "steady" pattern of growth	

FIGURE 4 Gento coordinates talk and embodied activity to describe how the guppy population would behave as it reaches the carrying capacity of the pond. Images of actions 8, 9, and 10 are shown in the right column.

there's (6) more more room for births so more more will grow then	(6) hands move upward
(7) then some will die and	(7) hands are lowered
(8) some will grow and	(8) hands are raised
(9) some die so it'll be	(9) hands are lowered
(10) steady.	(10) right hand moves up and down in a small range to show a "steady" pattern of growth

In this turn, Gento describes the "representing" world of guppies or how guppy population growth is represented mathematically (i.e., "It'll [the number of guppies] go up and down") and the "represented" or lived experience of guppies inhabiting a pond ("some would suffocate to death") (Hall, 2000). Gento's talk and gestures combine aspects of the physical representations he has used to understand guppy population growth in the pollution scenario (i.e., graphs created using the Habitech© software and the pond diagram) to explain what he thinks will happen to the population. In action (1) Gento moves his hands alternately up and down suggesting how the growth of the population would be represented on a graph. In action (2) he creates a flat surface with his hands to indicate the top surface area of the pond and in action (3), he rolls his hands up showing how oxygen is "take[n] up" from the pond. Through this complex coordination of talk and gesture, Gento connects the mathematical representation of guppy population growth with an understanding of the biological and environmental processes that constrain the size of the population.

Why Conjecturing is Important for Mathematical Generalizing

Conjecturing involves asking "What if?" Asking this question is important for generalizing because it pushes students to move beyond particular situations to make sense of new situations. The activity of conjecturing involves more than just predicting; it also involves explaining why something will happen. In this case, the students, with the help of the teacher, were generalizing about what happens when a population reaches the carrying capacity of its environment. As with the example of linking, the design of the problem the students were working on and the materials they were given to think about the problem provided important resources for generalizing. The diagram of the pond, which closely resembled a tank, allowed the students to determine the pond's carrying capacity and allowed the students to refer back to their understanding of how carrying capacity affects the growth of populations to understand a new situation that they had not considered. Through the activity of conjecturing, the students coordinated talk, gesture, and inscriptions like the diagram of the pond to gain access to situations and events that are not directly accessible in the classroom so that they can imagine and analyze the general behavior of objects and situations.

DISCUSSION

Research on mathematics and science has found that it is challenging for students to learn to use decontextualized or generalized language to reason about real and hypothetical situations (Lemke, 1990; Mason, 1996; Rowland, 2000). To understand how students generalize, this study examined how one group of students worked together to identify patterns and make predictions about simulated real-world problems in an extended population-modeling project. While the students did not always succeed in making broad generalizations that extended beyond the scope of the specific problems they were studying, this analysis highlighted aspects of the process of generalizing.

This study focused on participation frameworks to examine how a group of students coordinated talk, gestures, and inscriptions to generalize. Two participation frameworks, linking and conjecturing, were identified as ways that the students used to attempt to generalize about mathematical situations. Through linking a speaker proposes a comparison between situations and uses resources including talk and inscriptions to articulate and show the recipient the basis of the comparison. In so doing, the recipient is positioned to evaluate the comparison in a particular way. As discussed in this analysis, this process of comparing and negotiating similarities and differences can be a resource for identifying general patterns. Through conjecturing, this study showed how a speaker can invoke a "possible world" (Heath, 1991) that she/he can explore with co-participants. In imagining these possible or hypothetical worlds, participants use narrative and other modeling tools (e.g., graphs, computer simulations) to describe the behavior of phenomena over time, predict the effects of changes on the situation, and justify outcomes. From this perspective, a generalization is understood as the outcome of activities distributed across people, talk, and inscriptions rather than the product of any individual's thinking.

As shown in this study, the interactions between students did not always facilitate the kind of mathematics and generalizing intended by the curriculum designers or the teacher. For example, when Patrick wrote, "it's different" as an answer to whether a linear model of population growth is sensible, he was responding to the demands of getting an answer rather than pursuing a mathematical or a biological line of analysis. On the other hand, in their discussion of whether overpopulation was a finding or an error, the students pursued the meaning of their mathematical model by drawing on and integrating their prior work in the Guppies unit (i.e., research on guppies and populations) and their personal experiences with patterns of growth (i.e., patterns of weight fluctuations) to understand a new situation (John, Torralba, & Hall, 1999). While the differences in the students' approaches to these problems is beyond the scope of this analysis, one possibility for the difference may lie in how the students understood the problems in the context of their classroom activities. More specifically, the students' conversation about overpopulation was motivated by their own identification of a significant problem whereas the question about the sensibility of a linear population model was introduced by a worksheet question. When the students worked on the worksheet, the question of sensibility was not yet something that all of the group members considered a relevant question. By the end of the unit, however, after the students had spent more time discussing the realism of their own and other's models (in whole-class discussions and in conversations with visiting biologists), the students began to take on more of a concern for what they were modeling and whether it made sense (see Jurow, in press, for an analysis of how the relevance of problems develops in a similarly organized project). Developing detailed descriptions of the conditions under which students engage in meaningful mathematics will facilitate our analysis of how, when, and why generalizing takes place in classrooms.

Supporting Mathematical Generalizing in the Classroom

How can teachers engage students in mathematical generalizing in the classroom? Research suggests that students need to engage in and reflect on a variety of experiences over time to see the general connections between them (Bransford, Brown, & Cocking, 1999). In this study, students spent 8 weeks studying and creating models of guppy populations. They examined aspects of population growth through building and altering population models using dynamic software, analyzing the sensibility of different population models, investigating the growth of populations in different situations using multiple forms of representation (e.g., tables, graphs), and discussing and comparing their models in conversations with peers and professional biologists. Engaging in activities such as these is not enough for students to see the connections across activities or to begin to make mathematical generalizations. Students also need guided reflection and multiple scaffolded opportunities to talk about, write about, and otherwise represent what is general in and across situations (Greeno & Hall, 1997).

As prior research indicates, whole-class discussions can be a productive context for engaging in these conversations and activities. For example, in a series of whole-class discussions during an extended project such as the Guppies unit, the teacher and students can create a public and running record of the approaches used to solve different problems. Through guided reflection on the approaches, the teacher can ask the students to discuss and critique each other's approaches, try to make connections between their approaches to different problems, and attempt to identify general patterns that emerge from a comparison of different students' approaches and solutions. Teachers can also scaffold students' discourse by asking them to predict what will happen in a situation that is more or less similar to the one they are considering or come up with a rule that describes what always happens in a situation. By making conversations focused on generalizing a routine part of classroom practice, students will have more opportunities for identifying patterns, making predictions, and transferring their understandings into new situations.

CONCLUSION

Generalizing is usually thought of as an individual, cognitive process. It is often the case that teachers, curriculum designers, and textbook authors fail to recognize that general mathematical patterns are not directly perceptible. Mathematics students do not unproblematically see general patterns through exposure to or experience with multiple, similar cases. Rather, they need to orient to and be guided to recognize what is relevant in and across situations.

By conceptualizing generalizing as a situated activity, this analysis provided a productive way to look at the work involved in generalizing and the contexts in which generalizations emerge. Instead of studying what students ought to see and do, this analysis focused on what students *actually* see and do when they engage in mathematical activities. This study found that when students attempted to generalize they used talk, inscriptions, and embodied activity to identify the relevant similarities and differences between situations (*linking*) and to predict and explain what will happen in a situation (*conjecturing*).

The study focused on one group of students working on a project-based mathematics unit. However, the point of examining their activities was not simply to describe how this particular group of students attempted to generalize. It also aimed to describe a more fundamental dynamic involved in the activity of mathematical generalizing. The notion of generalizing in interaction, whereby generalizing is viewed as an accomplishment of people using talk, inscriptions, and embodied action to produce general claims, represents such a dynamic. The two participation frameworks described in this article were those used by one group of students in a single classroom. While focusing on one group can provide insight into the processes of mathematical generalizing, there is much more to be understood about these processes. How do students use and develop new resources (e.g., symbolic notation) to describe general mathematical patterns? How does generalizing in mathematics differ from generalizing in science? Studying how generalizing takes place in settings other than school (e.g., in scientific laboratories) can also shed light on the development of generalizations (see Hall, Stevens, & Torralba, 2002). The findings from this study recommend that future analyses of generalization attend to the processes of generalizing in interaction to describe *how* generalizations emerge in and through social practices.

ACKNOWLEDGMENTS

This research was funded in part by grants from the National Science Foundation and UC Berkeley's Graduate School of Education. The author thanks Rogers Hall, Frederick Erickson, Shailaja Menon, Clarissa Thompson, and Luis Urrieta for helping to clarify the ideas presented in this article. She also extends special thanks to Ms. Alessi, Gento, Andre, Patrick and Max for their participation in this study.

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