Designing and Investigating Dialogue-Intensive Online Math Videos

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In the past ten years, the number of web sites offering online math videos for K-12 students has proliferated, leading the Boston Globe (2011) to declare that "Math instruction has gone viral." There are many reasons for this explosion. Online math videos allow students to control of their rate of movement through material and to replay or skip sections based on their personal understanding (Lin & Michko, 2010). Children can gain access to more advanced mathematical topics than their peers in schools, if they are ready (Thompson, 2011). Finally, mathematics learning is within reach at anytime from anywhere, by virtue of the accessibility of the Internet and portable devices (Khan, 2012). Despite all these benefits to online math videos, there are some limitations in the types of videos currently available.

According to Hopper (2001) there is surprising uniformity in the mode of presentation and the nature of the content (Hopper, 2001). Specifically, "talking hands" or "heads" demonstrate step-by-step procedures using traditional pedagogical approaches (Bowers, Passentino, & Connors, 2012). A review of online mathematics videos revealed very few videos created for K-12 student learning that included dialogue with children ((Lobato, Walters, & Walker, 2016).). In these videos, either children mimicked the script of a traditional teacher, or animated characters were used to discuss how to resolve dilemmas. A number of excellent videos *do* show students engaged in problem solving and explaining their reasoning; however these videos were filmed to expose teachers to different images of mathematics classrooms, rather than to facilitate students learning from the videos (see, for example, Annenberg Learner's *Insights into Algebra*).

Consequently, our goal has been to develop videos that would insert a new voice into the discussion about what's possible in video-based online mathematics learning for K-12 students by creating student dialogue intensive videos that are also conceptually oriented. In this proof-of-concept endeavor, funded National Science Foundation, we created two model units. One unit is on parabolas for high school students and contains 10 video lessons, with each lesson consisting of 4 to 7 short videos. The other unit is on proportional reasoning. It is for upper elementary or middle school students and is comprised of 7 lessons. All of the videos feature pairs of students persisting to resolve mathematical struggles. See Figure 1 for a screenshot from one of the Project MathTalk videos (available at www.mathtalk.org).

Figure 1. Screenshot of a Project MathTalk Video

Design Principles and Theoretical Framework

A major design principle guiding the development of our videos was to feature a pair of secondary school students engaged in dialogue, as characterized by Alrø and Skovsmose (2004) as a conversation that involves the *quality of inquiry*, meaning that there is an interaction that aims to generate new meaning or to open up different ways of experiencing things. This design principle is framed by the theoretical assumption that dialogue is central to learners' enculturation into forms of academic argumentation and that it mediates thinking through exposure to the language of more capable others (Vygotsky, 1978).

Although dialogue is well accepted as an important tool for learning, the educational usefulness of watching dialogue has been a matter for debate. In the emerging literature on *vicarious learning*, which refers to learning by observing and engaging with video- or audio-taped presentations of other people engaged in learning (Chi, Roy, & Hausmann, 2008), there is some evidence that students who vicariously observe a dialogue outperform those who observe a monologue (Craig, Sullins, Witherspoon, & Gholson, 2010; Fox Tree, 1999; Muller, Bewes, Sharma, & Reimann, 2008). One the other hand, in one of the few such studies in mathematics, the vicarious learners did not use the video spontaneously when asked to solve a related task (Kolikant & Broza, 2011).

Several researchers have provided a theoretical argument for the benefits of vicarious learning. According to Wegerif (2007), such vicarious participation in a dialogic community may help learners take the perspective of another in a discussion, thus "expanding the spaces of learning" through digital technology. Because vicarious learners are not as emotionally involved in defending a position, they may be better able to focus on the content of what is being said (Mayes, Dineen, McKendree, & Lee, 2002; McKendree, Stenning, Mayes, Lee, & Cox, 1998).

The role of being a voyeur to a dialogue rather than a direct participant, involves an “epistemic detachment” (McKendree et al., 1998, p. 116), which involves an emotional and cognitive distancing from ideas and social demands. This does not mean that vicarious learners are not actively constructing knowledge but rather, the lessened emotional attachment may also lead to a lessened cognitive load, which allows students to reflect on the roles of the teacher and students in the dialogue and “view each from the other’s perspective” (p 117).

Design-based research often has twin goals: (a) creating an innovation through an iterative process of designing, getting feedback from users and revising, and (b) contributing to the accumulation of knowledge in the field by developing theory about particular learning processes (Cobb, Confrey, di Sessa, Lehrer, & Schauble, 2003). Thus, our goal in conducting vicarious learning studies is not only to examine the mathematical progress and experiences of vicarious learners engaged with our videos but also to contribute to theory about the nature of the vicarious learning process. The study presented in this paper provides evidence of the nature of vicarious learning as involving emotional investment rather than epistemic detachment, and as displaying some features of collaboration rather than voyeurism.

Methods

One pair of vicarious learners, Desiree and Belinda, was recruited from a previous study in which 13 pairs of high school students interacted with the first video-based lesson from Project MathTalk’s parabola unit (as described in Walker, Voigt, Lobato, & Walters, 2017). This particular pair was selected because they demonstrated understanding of the definition of a parabola in the first study and because they were willing to participate. In their regular Algebra 1 class, they were earning in the B to D range. Both were fluent in Spanish and English. The students were from a diverse high school (87% free and reduced lunch, 46.2% English learners) in a southwestern U.S. city.

The pair of VLs participated nine mathematics sessions, covering 8 video-based lessons from Project MathTalk's unit on parabolas. Each session lasted about 75 minutes and was video-taped. The vicarious learners sat at a table, where they had access to the MathTalk videos and could view the videos before, during or after working on a math task (see Figure 2 for the physical configuration).

Figure 2. Physical setting for the study: vicarious learners sat at a table where they viewed the videos and worked on math tasks.

The same researcher interacted with both the talent (the students appearing in the videos) and the vicarious learners (VLs; the students viewing the videos), but her role changed. When we designed the VL study, we considered two ends of a spectrum for the role of the researcher. On the one hand, we could try to recreate circumstances of an individual accessing these videos online at home, with little or no interaction with a researcher. However, we worried we wouldn't get a rich verbal trace to examine. On the other hand, the researcher could play the same role as she did when teaching the talent. However, we wanted the videos to serve as the primary source of instruction. Thus, we limited the researcher's actions to giving praise, presenting tasks, and asking the VLs what they noticed in the videos and to explain their reasoning on math tasks.

Sometimes the tasks were identical to those in the video, but to ensure a high level of problem solving for the VLs, we sometimes used paired tasks where the task given to the VLs differed slightly from the one the talent worked on, e.g., the parabola had different vertex or the axes were scaled differently. The researcher sat across the room while the VLs worked on the math tasks and watched videos. The VLs would call the researcher over to explain their reasoning to her when they were stuck or done. This meant that the researcher left many areas of confusion unresolved; in this respect the sessions resembled an interview.

The production of the math videos used in this study resulted from iterative cycles of design and feedback from users. We experimented with different camera angles, audio systems, video backgrounds, and ways to mix the different digital streams (overhead camera, main camera, student writing on Cintiq, and green screen image of students) before settling on a look for our videos. This process involved testing targeted features with any available users, and included filming several full lessons with practice students. We also conducted a focus test with 8 high school students.

Three features of the videos are described briefly. First, the teacher is off-screen; she is seen but not heard. This is in an effort to keep the focus on students' mathematical reasoning. Second, to highlight the talent overcoming struggles, as well as their important discoveries, we edited key moments and added voice-overed summaries of the students' discoveries. Third, we found during the focus test that users had difficulty discerning important mathematical features (such as the focus of a parabola) when the talent had created many points that competed for users' attention. Thus, we decided to annotate the videos in post-production to help future VLs (see the example in Figure 3, where the focus and directrix of the parabola are annotated).

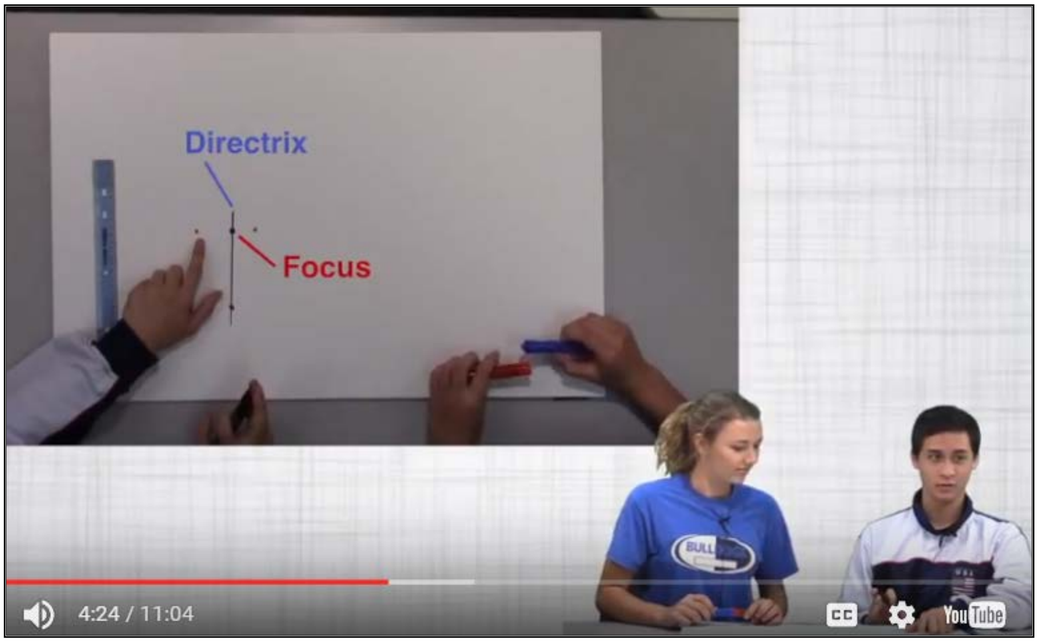

Figure 3. Example of annotations in the MathTalk videos, which were added during post-production

The parabola unit begins with the talent working together to make sense of the geometric definition of a parabola (i.e., a parabola is the set of points that are equal distance from a fix point, called the focus, and a fixed line, called the directrix) and to create a parabola from the definition. Then over the course of many lessons, the unit builds the machinery for students to derive the vertex form of a general parabola, which is $y = \frac{(x-h)^2}{4p} + k$ where the (h,k) is the vertex and p the distance from the vertex to the focus. A major theme of the unit is *quantitative reasoning*, where we follow Thompson (1994) in characterizing a quantity as one's conception of a measurable attribute of an object. In the context of parabolas, the quantity of interest is distance. When students grapple with how to create a parabola from its geometric definition, they have to figure out how to place points so that they are the same distance from the directrix as they are to the focus. When students create equations for parabolas on a coordinate grid, they need to represent distances using algebraic expressions such as y + 1. Thus, quantitative reasoning in the parabola unit encompasses connections between geometry and algebra.

The first analysis that we conducted was that of tracking the learning trajectory of the VLs' quantitative reasoning, as a result of interacting with the video (which is reported in Lobato, 2017). During that analysis, we kept noticing statements that the VLs would make about the nature of their engagement with Sasha and Keoni (the talent). Thus, for the study reported here, we viewed all 9 math sessions with the VLs again, this time recording, describing and transcribing each instance in which the VLs made any statements about the talent, comparisons of themselves to the talent, or general reflections on the videos. Then we use open coding from grounded theory (Strauss & Corbin, 1990) to cluster similar utterances together and name them with categories. Five categories emerged, which are presented next in the Results section.

Results

In this section, we present the following five categories of behavior from the VLs, which capture the nature of their engagement with the talent from the videos: (a) understanding the talents' mathematical personalities; (b) predicting the talents' mathematical actions; (c) coordinating activity with the talent; (d) acting as if the talent could engage with their work; (e) being in a community of learners. Together these categories paint a picture of the VLs' stance toward the videos and provide a window into understanding how the VLs positioned themselves toward the talent. In the Conclusion Section, we use the evidence presented in the Results Section to argue that rather than being positioned as detached voyeurs, the VLs act as if they are in a collaborative group with the talent (which we refer to as quasi-collaboration).

Understanding the Talents' Mathematical Personalities

The two vicarious learners, Desiree and Belinda, went beyond simply noticing and appropriating mathematical strategies and reasoning from the talent (Sasha and Keoni). They also frequently characterized Sasha and Keoni's personalities as problem solvers. It was as if Desire and Belinda were striving to assess what roles and kinds of mathematical competencies (Lotan, 2003) Sasha and Keoni could bring into a collaborative group consisting of the four of them.

For example, the VLs noted that Sasha liked to generalize methods and create shortcuts, whereas Keoni tended to approach problems methodically and derive answers carefully and repetitively. Specifically after watching Keoni approach a problem (Session 3, 01:07:47), Desiree exclaimed "He went the long way, as usual…there is nothing new about that!" This suggests that Desiree had noticed patterns in Keoni's behavior that characterized his general approach to many tasks in the unit. Later, in Session 6 (00:01:25-00:01:42), the VLs went a step further by relating themselves to Sasha and Keoni:

Belinda:	It's like I am Keoni and you are Sasha, because I always want to do it the long way.
Desiree:	Yes!
Researcher:	You identify more with Keoni [points pen to Belinda] and you [turns and points to Desiree] identify more with Sasha?
Both VLs:	Yeah. Yeah.
Researcher:	Just because of short, long way or other reasons too?
Desiree:	Not only that. She [Sasha] always likes to go for something bigger and I am just trying to do it the short way and get it right away.

These statements suggest that the VLs not only learned to characterize some of the ways in which the talent tended to approach problems, but they personally identified with the talent. As another example, consider Session 3 (00:53:28 – 00:54:01), when the VLs were struggling to use a complex method to derive an equation. Desiree made a case that the long way may not work. As Belinda tried to counter her argument and stick up for the long way, Desiree cut her off and teased, "You just want to be like him [motions to Keoni in the video and laughs]!"

It is interesting to note that most of these types of exchanges occurred during the first three sessions of the study. Once Desiree and Belinda got to know their new "group members," they began to work with them as if they were peers in the room with them.

Predicting the talents' mathematical actions

Once the VLs understood the talent as mathematical problem solvers and picked up on particular methods that the talent used, they could often predict what Sasha and Keoni would do before watching them. Similarly, they commented when the talents' actions did not meet their expectations.

For example, in Session 1, the VL's had noticed how Sasha used circles to count units on a coordinate grid. As shown in Figure 4, Sasha determined that the distance from the point (4, 4) on the parabola was 5 units to the directrix by circling each of five unit-length segments on the coordinate grid. Later, during Session 8 (00:17:06 – 00:17:11), the VLs were watching the talent explain how to determine the coordinates for a point on the parabola that were aligned horizontally with the focus (see the point ($2p$, p) in Figure 5a). First Keoni used the method of "Sasha's circles" to indicate where he saw the distance p in the graph (as shown in Figure 5a). Then Sasha added a line segment (as opposed to a circle) to represent another distance p (see Figure 5b), at which point Desiree turned to Belinda and said, "I thought she [Sasha] would use the circles."

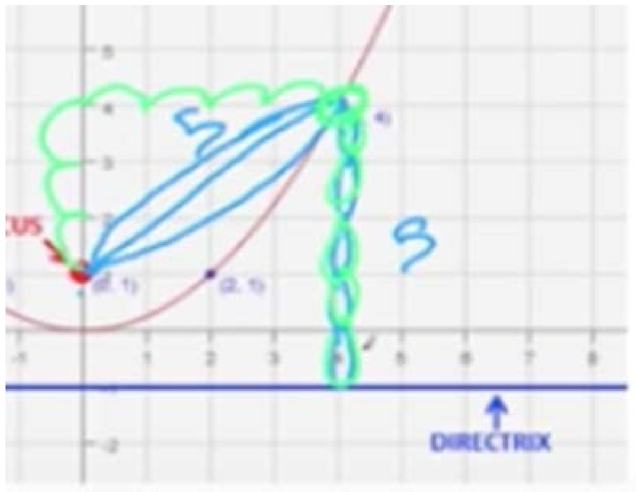

Figure 4. Screenshot from the MathTalk videos, Parabola Unit, Lesson 2

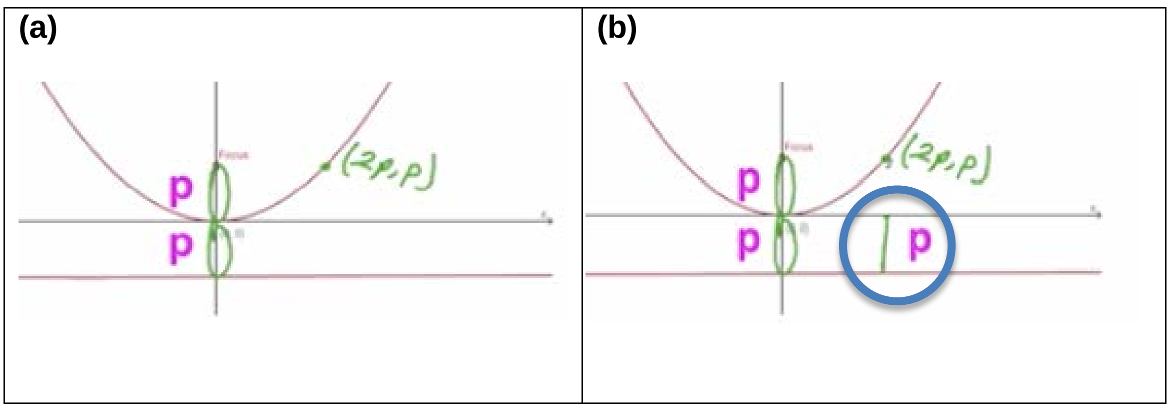

Figure 5. The talent marked distances of *p* units using (a) circles, and (b) line segments.

Coordinating Activity with the Talent

Barron (2000) argues that central to collaboration is a process in which "students organize themselves to engage in coordinated activity" (p. 404). Coordination includes paying attention to ideas of all group members, comparing one's work to others, and keeping track of what has been said. It is central to the development of knowledge in the common ground. Of course, it is not possible for Sasha and Keoni to resolve any discrepancies in understanding they may have with the VLs; thus, true common ground is impossible to establish in a vicarious learning situation. However, it is interesting that the VLs engage in many activities of coordination, as if they are trying to establish common ground with the talent.

For example, there are multiple instances when Desiree and Belinda compared their work to the talent. Table 2 gives a flavor of the types of comparisons that they made.

Table 2.

Statements by Vicarious Learners	**Location of Utterance**
Desiree: She [Sasha] made the same mistake as us!	Session 7, 01:01:37
Desiree: Look, they rounded off too!	Session 7, 01:04:20
Belinda: They [Sasha and Keoni] have new edits too!	Session 6, 00:45:05
Desiree (to Belinda): She [Sasha] said the same thing as you (smiles)	Session 8, 00:13:27

In contrast to the detached consideration of various ideas expressed in the videos, as suggested by McKendree et al. (1998), the VLs aligned themselves with talents' methods and mistakes. They also appeared to engage in an emotional manner. For example, Belinda and Desiree giggled when they watched a video in which Sasha and Keoni made the same type of scaling error that had plagued them throughout Sessions 1-5. They giggled again when Sasha caught her error. They noticed and reacted to their shared errors as if they were satisfied that the talents' mistakes converged with their own.

Acting as if the Talent could Engage with their Work

Whereas the category of coordinating activity involves the VLs tracking the work of the talent, this category is about attributing collaborative actions to the talent (even though the talent can't perform them). In the instances that comprise this category, the VLs act as if the talent are in the room with them.

For example, in Session 5, the VLs had just finished watching a video and had called the researcher over to their table. The researcher asked the VLs what they noticed in the video.

Desiree immediately exclaimed, “They copied our graph”! (Session 5, 00:58:38). Laughter ensued. Obviously Desiree knew that her statement wasn’t true. Yet, it suggests that she positioned Belinda and herself *as if* the talent were in the room with them and had access to their work and ideas.

In a second example from Session 4 (01:17:44 – 01:18:20), the VLs had just completed watching a video episode in which the talent were asked to make predictions for the equation of the blue parabola shown in Figure 6, after finding the equation for the red parabola. Keoni incorrectly thought that both parabolas could have the same equation. This was not a difficulty experienced by the VLs. The talent struggled to use the points on the two graphs (as shown in Figure 6) to determine whether or not the two parabolas could share the same equation. In the transcript that follows, Desiree points to the video screen and tells Sasha about a pattern that she wants her to see:

Researcher:	Anything else that you want to tell me that you noticed in this episode?
Desiree:	They’re slow (laughs)
Belinda:	(laughs)
Desiree:	It’s like, from right here it was
Belinda:	Like, I would think they would notice because they are further apart, so you would know that the numbers would be different
Desiree:	Like right here it was 2 comma 1 [points to (2,1) on graph, as shown in Figure 6], like how can you not notice it’s multiply by 2 right there… I even whispered to her [turns body toward Belinda], I was like [positions herself to look at screen and points to Sasha with pen] multiply by 2!

When Desiree exclaimed, “I was like, multiply by 2!” her body was positioned toward the computer screen and she was pointing her pen at Sasha in the video. This suggests that she was telling Sasha what to do, even though, obviously Sasha couldn’t hear her, since the videos were filmed months previously. But Desiree was acting as if Sasha is in the room and could build upon the pattern that Desiree noticed.

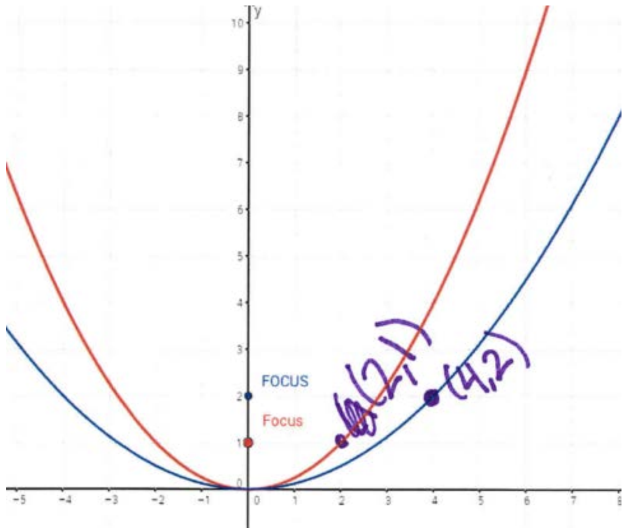

Figure 6. Two parabolas from the MathTalk videos.

Being in a Community of Learners

At multiple points in the study, the VLs made statements that suggest that they felt part of a community with the talent, had a sense of being in the endeavor together, and believed they were struggling together. In particular, a common theme was one of the apparent pain of feeling alone in a math classroom when one is confused. Sasha and Keoni seemed to help alleviate that pain. That is, being part of a community of learners means that your confusion is shared.

For example, consider an interchange that occurred near the end of Session 6 (1:06:43 – 1:07:39), after the VLs had watched an episode in which Sasha and Keoni were confused. The researcher asked the VLs if they would rather see videos that included the talents' confusion or videos in which the talent showed the right way to do the problem without any confusion. Both girls said that they would rather see the confusion. Desiree explained that "Sometimes you feel like you are the only one [confused] and you're like the alien." She went on to recount an experience in her math class where she was confused and felt "like the only alien there." She continued to suggest that her feeling of isolation is common to many students because "there's always someone confused at one point." This theme recurred. For example, in Session 9

(1:21:35-1:21:46), Desiree was reflecting on confusion again and stated, “When I get really confused, I get isolated, like I’m the only one, but then knowing that she’s [Sasha’s] confused too …we’re both confused.”

These instances speak of the uncomfortable feeling of being alone in one’s confusion while sitting amongst a roomful of classmates. Desiree and Belinda seemed to be saying that by seeing other kids confused, you can feel part of a community of learners. Furthermore, Desiree seemed to be speaking beyond just herself and Belinda when she said “there’s always someone confused at one point.” Perhaps this means that even if she and Belinda are not confused, there will be other viewers in the future who will benefit from seeing that kids like Sasha and Keoni are confused too. In other words, it’s not just that one can learn by seeing the talent resolve a particular struggle; seeing the authentic confusion of one’s peers can help one feel normal and part of a community of people with shared experiences.

Conclusion

The evidence provided in this paper suggests an alternative hypothesis to that of vicarious learners as epistemically detached. Instead of being voyeurs, they seem to be quasi-collaborators with the talent in the videos. Staples (2007) makes a distinction between collaboration and cooperation. She claims that collaboration does not simply mean the sharing of solution strategies (cooperation), but rather a co-construction of ideas, where concepts are developed by the whole class building on each other’s understanding. It seems like Belinda and Desiree were acting *as if* Sasha and Keoni were present with them and could access and build upon their work. The VLs demonstrated several elements of collaboration, such as assessing the intellectual tools and general approach of the other group members (i.e., Sasha and Keoni), forming alliances, making comparisons between methods used by different group members, tracking progress, and coordinating activity in the group. Furthermore, rather than exhibiting emotional distance, the VLs seemed emotionally invested in Sasha and Keoni and felt better about their own mathematical experiences as a result of being in a community with them. Perhaps this emotional attachment is crucial for building trust in the talent, which in turn, contributes to the VLs' willingness to turn to the talent (via the videos) when they need help.

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