COMPUTER-SUPPORTED COLLABORATIVE VIDEO ANALYSIS OF TEACHING AND LEARNING

by

ESTHER WINTER

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ABSTRACT OF THE DISSERTATION

Computer-Supported Collaborative Video Analysis of Teaching and Learning

By ESTHER WINTER

Dissertation Director:

Dr. Carolyn A. Maher

The process of intersubjective meaning making is an important characteristic of learning which occurs through social engagement. However, little research has been conducted to explore how the collaborative analysis of video, particularly through the use of video-editing tools, can be used to support mathematics teacher education and research. This study examines the process of intersubjective meaning making and information uptake that was enacted by teachers, teacher educators, and researchers as they interacted with reviewers or peers while creating or modifying VMCAnalytics (video narratives) related to mathematics teaching or learning. The study was designed as a qualitative descriptive case study involving six novice or expert authors developing or revising VMCAnalytics for multiple purposes. Uptake analysis methodology was used for the analysis. The study offers deeper insight into the ways in which computer-supported collaborative video analysis is enacted, addressing the need for research in this area. Analysis revealed that most authors took up the majority of the reviewers' comments and that the quality of their VMCAnalytics improved over the course of the review process. However, discourse and uptake patterns as well as the quality of the final VMCAnalytic product differed between users, and some types of discourse had a larger impact on the quality of VMCAnalytics than others. This study also identified strengths and weaknesses of the VMCAnalytic tool as it is used for the review process prior to publication. These findings have implications for the future refinement of the tool that has potential to become a model for video research collaboration.

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CHAPTER 1 INTRODUCTION

Many researchers view social processes as a central component of learning (Brown, Collins, & Duguid, 1989; Greeno, 1989; Lave & Wenger, 1991; Vygotsky 1978; among many others). The process of intersubjective meaning making is an essential element of learning which occurs through social interaction (Lave & Wenger, 1991; Piaget, 1977; Rogoff, 1997; Tudge, 1990). Thus, understanding the process of intersubjective meaning making and how it supports learning is vital.

Technology has afforded learners with new ways of negotiating shared meaning and achieving intersubjectivity (Suthers, 2006b). One important technological tool, the VMCAnalytic tool (located at https://rucore.libraries.rutgers.edu/analytic), enables users to build narratives from video and provides a powerful means of enhancing users' attention to video and enables teacher educators and researchers to create artifacts to support their teaching and research. There has been much research conducted to explore the significance of using video for teacher education and research has revealed the value in utilizing video and video annotation tools for teacher education and research (Bryan & Recesso, 2006; Hauge & Norenes, 2009; Hmelo-Silver, Maher, Agnew, Palius, & Derry, 2010; Maher, Landis, & Palius, 2010; Maher, Palius, & Mueller, 2010; Palius & Maher, 2011; Preston et al., 2005; Rich & Hannafin, 2008; Schmeelk & Sigley, 2012; Shepherd & Hannafin, 2008; Sherin & van Es, 2002, 2005, 2006; Tripp & Graham, 2009; Tripp & Rich, 2012; Wright, 2008, among many others). However, there is a need for research that explores how the collaborative analysis of video using video-editing tools can be useful for supporting mathematics teacher education and research.

This study explores the process of intersubjective meaning making and information uptake as mathematics teachers, teacher educators, and researchers engaged with reviewers or peers as they developed and revised VMCAnalytics. In particular, the study investigates how VMCAnaltyics evolved, how users engaged with reviewers or peers during the process of multimedia artifact development and revision, how they took up the ideas of others as reflected by their online or face to face discourse as well as by their modification of multimedia artifacts, and how users with different goals, backgrounds, or expertise levels differed in their interaction and uptake processes. Uptake analysis was employed to support this analysis.

The study offers deeper insight into the ways in which computer-supported collaborative video analysis is enacted, addressing the need for research in this area. It found that most authors took up the majority of the reviewers' comments and that the quality of their VMCAnalytics improved over the course of the review process. However, discourse and uptake patterns as well as the quality of the final VMCAnalytic product differed between users, and some types of discourse had a larger impact on the quality of VMCAnalytics than others. This study also identified strengths and weaknesses of the VMCAnalytic tool as it is used for the review process prior to publication. These findings have implications for the future refinement of the tool that has potential to become a model for video research collaboration.

CHAPTER 2 THEORETICAL FRAMEWORK AND LITERATURE REVIEW

Video has been used in teacher education since the 1960s when technology became affordable and portable enough to be feasible for use in the classroom (Sherin, 2004). Over the decades, video has been used in many different ways for teacher education, reflecting both changing philosophies of education as well as technological advances, and hundreds of studies have been conducted to analyze the use of video in teacher education (Maher, 2008; Sherin, 2004). The present study centers on analyzing the socially mediated construction of multimedia artifacts by researchers, teacher educators, and teachers. In particular, the study investigates how VMCAnalytics evolve as authors negotiate meaning through their use of a newly developed VMCAnalytic commenting feature and how such discussion during the revision phase contributes towards the final VMCAnalytic product. In order to situate this study, this review will discuss some leading theories of learning which account for how learning is supported by social processes as well as research which has been conducted to explore the learning that occurs in social contexts. Literature related to the use of video for teacher education will be examined since the videos of the Video Mosaic Collaborative (VMC) projectand the RUanalytic tool are used for both research as well as teacher education. Additionally, since the RUanalytic tool is part of the larger VMC project which is described in more detail below, this review will investigate the studies related to the VMC which have been conducted to date. Additionally, it will consider studies involving the RUanalytic tool, the specific tool which will be considered in my investigation, as well as ways in which other video annotation tools have been studied thus far.

2.1 Supporting Learning with Social Processes

2.1.1 Foundational Theories

There are several foundational theories which account for how social processes are involved in learning: social constructivism based on the research of Piaget, socio-cultural theories based on the work of Vygotsky, and theory of situated cognition which views learning "as a process of entry into a community of practice" (Koschman, 1996, p. 14) developed by researchers including Brown, Collins and Deguid (1989), Greeno (1989), and Lave and Wenger (1991). These foundational theories are discussed in the sections which follow.

2.1.1.1 Piaget's Sociocognitive Conflict Theory

Piaget (1939/1965; 1985) described a process of cognitive development, which recognized that learning occurs through social interaction since social interaction acts as a strong source of disequilibrium and cognitive change by encouraging a child to reexamine his own beliefs by introducing cognitive conflict.

Piaget (1939/1965) maintained that collaborating with peers is superior to interacting with more competent others or members with a perceived differences in status since each participant is capable of influencing the other, allowing for argument and discussion which can lead to cognitive restructuring. When learners' thoughts are constrained by views which are imposed upon them and are not afforded the opportunity to challenge their own beliefs, learners will not have the opportunity to experience cognitive conflict and thus will not undergo cognitive growth.

Piaget (1977) proposed that there are three pre-conditions necessary for equilibrium to be realized from social interaction. First, members must share a common language in order to process opposing views of others in language they understand. Second, members must try to reconcile or explain differences in opinion. Third, members must seriously consider each other's ideas.

2.1.1.1.1 The Piagetian Tradition

Piagetian scholars have focused on interactions between peers who provide differing perspectives during interaction, inducing cognitive conflict. For example, Inhelder (1974), who collaborated extensively with Piaget, found that cognitive growth can be induced by introducing reasoning which is in conflict with a learner's existing schemas, providing opportunity for the learner to reevaluate and update her schemas. Researchers in the Piagetian tradition consider the individual as the unit of analysis rather than the dyad and concentrate their analyses on the results of collaboration on learners' cognitive schemas. They therefore emphasize the outcome of collaborative interaction rather than its process.

Studies based on the Piagetian view have supported the perspective that working with peers is beneficial (Light & Littleton, 1998; Slavin, 1990). Many researchers have investigated the effects of collaboration on cognitive conflict in the context of conservation tasks and have found that cognitive conflict can have a strong influence on cognitive development (Ames & Murray, 1982; Bell, Grossen, & Perret-Clermont, 1985; Murray, 1982; Perret-Clermont, 1980). For example, Bell et al. (1985) analyzed cognitive change from the socio-cognitive conflict perspective, investigating how social interaction introduces cognitive conflict, providing opportunity for a restructuring of cognitive schemas to promote cognitive growth. They examined children's growth in multiple Piagetian operatory tasks involving conservation. They found that when children were actively engaged in collaboratively solving a problem and when the children were on similar cognitive levels, they exhibited greater cognitive growth than those working alone. Formerly “non-conserving” children who worked with “conserving” peers not only made claims of conservation in a post-test, but also used new justifications to elaborate on their arguments. The experiments found that even when the information causing the cognitive conflict was incorrect, it nevertheless prompted cognitive restructuring and progress. Additionally, conflict resolution was not necessary for growth. What was necessary for cognitive growth was the presentation of an opposing viewpoint during the partner interaction, which stimulated a cognitive conflict. Such studies support the notion that the presence of cognitive conflict during collaboration acts as an impetus for learning.

2.1.1.2 Vygotsky’s Sociocultural Theory

According to Vygotsky (1978; 1981; 1987), social interactions are the primary source of higher mental processes in individuals and promote the development of higher cognitive function, with development first occurring “on the social plane, and then on the psychological plane” (Vygotsky, 1981, p. 163).

Vygotsky (1978) asserted that learning can best be understood by examining the process as it occurs in development, or by using a genetic approach. He wrote, “We need to concentrate not on the *product* of development but on the very *process* by which higher forms are established” (p. 64). According to Wertsch (1985), Vygotsky maintained that without genetic analysis, it is impossible to understand the “inner workings and causal dynamics” (p. 18) of mental processes.

Wertsch (1991) identified three ways in which Vygotsky explained the relationship between individual and social factors in learning. The first is that individuals learn from working with others by gaining strategies and knowledge as they work together. The second is that semiotic means, which include language, writing, drawing, and symbols, aid humans in co-constructing knowledge and are used by individuals to internalize knowledge. The third is that social construction of knowledge is best studied in a developmental or genetic fashion, or as it undergoes change.

From Vygotsky's (1987) perspective, the study of cognitive development equates with studying interactions with others and how they influence later interactions. Since humans learn as part of a social context, Vygotsky proposed that learning should be analyzed through a unit of analysis larger than the individual, one that would preserve "all the basic characteristics of the whole" (Vygotsky, 1987, p. 46). Thus, the individual within the social interaction is considered as the unit of analysis rather than the individual and his specific characteristics.

2.1.1.2.1 The Vygotskian Tradition

Vygotskian scholars have tended to focus on the interactions between adults and children instead of peer interactions (Wertsch, Minick, & Arns, 1984), although some have studied peer interaction as well, focusing on the history of developmental behavior in achieving shared understanding (Forman & Cazden, 1998). They have also emphasized the importance of the process of the interaction rather than the outcome of the interaction. This is because the Vygotskian tradition emphasizes that the process which an adult uses while solving a problem interactively with a child is more important than the solution itself (Wertsch, 1985). Moreover, Vygotskian scholars consider the unit of analysis as larger than each individual who is engaged in collaboration since learning cannot be divorced from the context in which it occurs. For example, Leont'ev (1974), who had worked with Vygotsky, suggested activity as the unit of analysis. Activity theory focuses on instruments, methods, rules, symbols, signs, and other artifacts that mediate activity (Koschman, 1996). Tudge (1990) argued for consideration of the dyad as the unit of analysis in order to support the study of the process of collaboration.

According to Tudge (1990), Vygotskian scholars stress the importance of intersubjectivity in effecting cognitive change. Intersubjective meaning making is a process in which people work together on a common activity, starting with shared presumptions and moving towards shared understanding by making sense of what other group members are saying. Tudge (1990) found that achieving shared understanding was crucial in effecting cognitive change. Rogoff (1997), too, stressed that in order for collaboration to succeed, intersubjectivity must be established between members of the collaboration. Intersubjectivity refers to the shared meaning that people construct between themselves as they communicate with each other. According to Rogoff, achieving intersubjectivity leads to growth of understanding, since in order for people to coordinate meaning they need to modify their own perspectives.

Studies based on the Vygotskian view have supported the perspective that working with a more competent partner is beneficial (Tudge, Winterhoff, & Hogan, 1996). Studies have also found that children gain more from adult interaction than from peer interaction (Radziszewska & Rogoff, 1988; Rogoff & Gauvain, 1986). Based on their findings they maintain that it is important that the child perceive the collaborating other as more competent than himself. Additionally, their studies have shown that successful collaborative achievement in a task precedes a child's ability to complete the activity alone, supporting the notion that collaborative development precedes an individual's cognitive development.

2.1.1.3 Situated Learning and Communities of Practice

Another framework that is useful for understanding how social processes account for learning is that of situated learning. This framework and the related framework of communities of practice establish methods of analyzing how meaning and identities are negotiated in practice.

According to Lave (1991), situated learning considers social and cultural relations as the starting point, or the creators of, learning and knowledge. Similarly Brown, Collins, and Duguid (1989) asserted that knowledge and learning are situated in experiences and gained from everyday situations. Therefore, they contended that it is important to understand the settings in which learners gain new knowledge. According to this model, concepts are continually developed through activity and are not abstract, but rather are understood from their situational contexts and cultures. The view that learning is situated in a culture and a society gives rise to the idea of communities of practice (Lave, 1991). These communities are the hubs of knowledge creation, as they provide the social and cultural context that enables learning to take place. Lave and Wenger (1991) conceptualized communities of practice as a theory of learning which describes individuals who share mutual understanding over a period of time while pursuing a particular enterprise. This theory describes how meaning is negotiated in practice through participation and reification and how participation in a community of practice shapes the identities of those participants, with new participants starting out on the periphery of the community and gaining fuller participation over time as they gain knowledge.

According to Wenger (1998), participation in a community of practice is effected through the actions of members of a social community which mutually affect others' experiences of meaning. Participation not only creates meaning for members, but also helps shape the practices of the community. Reifications are the processes or end products of processes through which members perceive their own meanings as existing as a reality in the world and reflect the underlying practices that brought them into existence. Participation and reification interact with each other, as participation ensures that reifications are not misinterpreted, and reifications bring uniformity and conformity to participants. Practice thus creates cohesiveness within a community. Additionally, learning is interwoven with the identities that participants take up in practice. Identities are created in communities of practice through proficiency that is acquired by becoming members of the practice, and they are sustained even when members are not actively participating in the practice. Identities evolve as members' positions in the community change over time through various trajectories.

Wenger (1998) argued that engagement in practice is a primary source of learning. Similarly, Brown and Duguid (1991) asserted that learning is a process that occurs through work and practice because learning in the workplace involves becoming a member of and learning to function as part of a community of practice. The design of learning environments, therefore, must allow for students to be engaged in a community of practice as a way of learning the subject matter, and social relationships must be incorporated into the learning process. They therefore advocated that learners should have access to the communities of practice which they are being trained to join and should be able to observe the work of the participants of those communities. Since knowing and doing are interconnected and activities are what engender learning, Barab and Duffy (2000) advocated that learners should be involved in actual activities related to their domain and relevant to real-life situations instead of learning about the findings of others. The role of the teacher is not to teach content but rather to guide the students in finding solutions on their own. After gaining new knowledge, students should reflect upon the experience and what they have learned.

Brown et al. (1989) agreed that learning involves the acculturation of students within communities and necessitates the ability of students to use tools in the same ways that members of a community use them. Since learning involves a process of enculturation, Brown et al. (1989) asserted that much of formalized school learning cannot be considered authentic learning because even when students work on tasks derived from practice, they are transformed by the school culture and the original context of the task is thereby altered. However, social interaction can counteract this effect and help promote enculturation. Therefore, group collaboration, with participants playing multiple roles, is an important component of learning.

Barab and Duffy (2000), too, stressed that situated learning theories emphasize collaborative work on problems and the negotiation of meaning in practice. Additionally, communities of practice signify the existence of a community with shared practices and history, the connection of the community to something larger, and the opportunity to learn from more experienced members to enable members to transition from being peripheral members to full participants. Instead of viewing education as preparation for future activities, the theory of communities of practice views education as meaningful in and of itself and requires connecting to society through students' participation in a community via the execution of relevant tasks. According to this approach, learning accomplished as part of a community is considered the most effective form of learning. Stein (1998) added that communities of practice involve the merging of analysis and reflection to allow for the creation of shared knowledge during a learning opportunity. Members of a community of practice each possess related bodies of knowledge that are an essential part of the community, one with which new members must interact.

2.1.1.3.1 The Communities of Practice Tradition

Literature describing the benefits of implementing the communities of practice model in education has focused on its utility for professional development (Buysse, Sparkman, & Wesley, 2003; Schlager & Fusco, 2003). Instead of viewing researchers as those creating knowledge and practitioners as consumers of that knowledge, the lens of communities of practice views both researchers and teachers as contributors to a common knowledge base as well as utilizers of that knowledge. Integrating practice with research in this way is important to ensure that research leads to insights that inspire relevant educational policies and practices. Communities of practice offer a good model for collaboration between researchers and educational practitioners because this model fosters mutual trust and long-term relationships which enable both groups to co-construct knowledge and improve practice.

Researchers have used the concepts of communities of practice in understanding teacher education by viewing teaching as a practice which develops the identity of the individual as a teacher through participation in a community of practice involving teachers, teacher educators, and researchers. According to Cestari, Daland, Eriksen, & Jaworski (2005), teachers and researchers must collaborate as well as reflect upon the practices of the community. Cestari, et al. tried to identify ways that the two communities of teachers and teacher educators can better be integrated into a single community of practice. They conducted a qualitative study of workshops conducted by researchers for teachers and of groups in which researchers guided teachers in designing classroom tasks. They analyzed conversations from teacher mathematics education workshops in an effort to better understand how the practice is affected by the discussion of roles and how the perspectives of the participants affected their interactions with other members of the group. Although education development has often been seen as a "top-down" process, with researchers directing teachers regarding best practices in their classroom, Cestari et al. found that through using terms such as facilitators or coordinators to refer to researchers, this attitude can be changed to promote the development of a true community of practice involving both teachers and researchers.

2.1.1.4 Unifying the Perspectives

According to Rogoff (1977), one major point of intersection between the perspectives of Piaget and Vygotsky is the emphasis that both place on the "achievement of shared thinking" (p. 681). Likewise, the theory of communities of practice emphasizes the negotiation of meaning to achieve shared understanding. Although many Piagetian scholars have focused on cognitive conflict as the locus of cognitive growth during collaboration and on the outcome of interaction, (Ames & Murray, 1982; Murray, 1982), many have also recognized the importance of shared understanding during interaction and the process of the interaction (Light & Perret-Clermont, 1989; Perret-Clermont, Perret, & Bell, 1999). As mentioned, Piaget (1977) proposed that members of an interaction must share a common language, attempt to reconcile or explain differences in opinion, and seriously consider each other's ideas. Similarly, Vygotskian scholars stressed the importance of establishing intersubjectivity in order to effect cognitive change, since by coordinating meaning, members necessarily modify their own perspectives (Tudge, 1990). Shared understanding is even more central to the theory of communities of practice. The theory of communities of practice is fundamentally a theory of learning that describes individuals who share mutual understanding and negotiate meaning in practice through participation and reification. Thus, all three perspectives account for the importance of achieving shared understanding for learning.

Damon (1984) attempted to reconcile the differences between the Piagetian outlook, which emphasizes the benefits of peer collaboration, and the Vygotskian perspective, which emphasizes the superiority of child-adult interactions. He suggested that in situations in which the learner must change his perspective and either alter schemas or build new schemas, interaction with peers is beneficial in effecting such paradigmatic shifts. However, in situations in which the learner must merely improve his skills without changing his perspective, interaction with an adult may be more beneficial.

The theory of communities of practice, likewise, accounts for differing identities in practice. Participants benefit from interacting with all other participants, whether full or peripheral. Thus, learning occurs from interaction with both more experienced as well as equally experienced members.

Many of the differences between the theories are not mutually exclusive and it is therefore possible to incorporate elements from all perspectives into an educational approach based on the social construction of knowledge. For example, some scholars have investigated both the process of interaction as well as the product (Light & Perret-Clermont , 1989; Perret-Clermont, Perret, & Bell, 1991).

Additionally, cognitive conflict can be viewed as a means for promoting a child's development within his zone of proximal development. Along these lines, Fawcett and Garton (2005) suggested that the Piagetian and Vygotskian perspectives can be made complementary through the support they each provide to the advantages gained by a child who receives explanations from a partner. According to Vygotsky, this benefit occurs when a more competent partner helps the child gain knowledge by assisting with problem solving or promoting understanding. According to Piaget, a child gains from explanations which stimulate cognitive conflict and prompt the child to construct more elaborate schemas. Fawcett and Garton argued that in order for collaboration to be effective, the partners must be actively involved in the interaction and one partner must be more competent and present a different point of view in order to cause cognitive conflict and expose the child to new information within his zone of proximal development. In support of their view, they found that children who were paired with more competent peers who explained their thinking in a sorting activity gained most from the interaction. Thus, the benefits of both cognitive conflict as well as guidance within the ZPD can potentially be supported simultaneously.

Similarly, Kruger (1993) proposed that collaboration produces benefits when aspects from both Piaget's and Vygotsky's perspectives are combined and the child works with a partner who provides a different viewpoint, either because he has more knowledge or because he has an opposing perspective. The collaboration can involve both socio-cognitive conflict as well as co-construction of knowledge. Socio-cognitive conflict can occur when the child realizes that the partner has a differing perspective, and co-construction of knowledge can occur as they work together to coordinate their viewpoints. For both perspectives, it is important that the partners discuss the differences in their viewpoints and the basis of these differences.

2.1.1.5 Summary

The theories of learning described in the preceding sections maintain that knowledge is socially constructed. Socio-cognitive conflict theory explains that cognitive conflict leads to learning and focuses the analysis on the outcome of interaction. Socio-cultural theory maintains that cognitive development occurs through the internalization of social activities. The focus of analysis in this tradition is the process of social interaction as it occurs in development and considers effective interactions as those which encourage a learner’s potential development within his or her ZPD. The learner gains knowledge and internalizes skills which lead to conceptual change. Researchers of this tradition have focused on the achievement of intersubjectivity. The theories of situated learning and communities of practice maintain that learning is situated in experiences and that communities of practice provide the social context that enables learning to take place. According to this tradition, engagement in practice is a primary source of learning as meaning is negotiated in practice through participation. All these theories emphasize the value of shared thinking and the negotiation of meaning to achieve intersubjectivity.

2.1.1.6 A Framework for the Current Study

This study analyzes the influence of invited feedback on the evolution of constructing VMCAnalytics. Specifically, it explores how feedback from experts and peers help shape final VMCAnalytic products. Collaborators worked with authors to help them build coherent video narratives with specific goals and objectives. These goals included the telling of a story that traces learning or the creation of conditions that lead to learning. While the goals of authors varied, narratives showed evidence of how specific theories about the teaching or learning of mathematics are evidenced in practice. As authors created and then revised VMCAnalytics based on feedback, they learned more about the mathematical ideas they analyzed in their VMCAnalytics, the theories which they used as a basis of their VMCAnalytics, how the theories are evidenced in practice, as well as the norms of video analysis and VMCAnalytic authorship that have been adopted by a community of researchers who make use of the RUanalytic tool. Thus, learning was supported in multiple ways and multiple theories of learning are useful for understanding the learning that occurs.

When reviewers provided feedback that conflicted with authors' ideas either about mathematics, theories of learning, or how video evidence supports those theories, authors may have experienced cognitive conflict which stimulated the creation or modification of mental schemas. Discussion may have therefore led to cognitive restructuring as collaborators considered each other's ideas, worked to reconcile differences in opinion, and modified their work and perhaps their perspectives. Additionally, authors gained strategies and knowledge from more knowledgeable experts who provided feedback. In order to recognize the effect of cognitive restructuring, studying the product of cognitive change as evidenced by the VMCAnalytic itself was necessary.

In order to gain a full understanding of how collaboration affected the development of a VMCAnalytic, it was important to study the process of particular interactions and how these influenced later interactions and actions. The VMCAnalytic is viewed as an artifact that acts as a mediator of activity, and it is from this perspective that the tool was studied as the semiotic means for assisting in the co-construction and internalization of knowledge. Thus, this study considered how users negotiated meaning through the mediation of the RUanalytic tool and the process of social interaction as authors and reviewers discussed data from the VMCAnalytics and how these discussions affected later interactions, modifications, and actions within the video narratives revealed with the RUanalytic tool. There are benefits to the process of input and mediation, as mentioned previously. Fawcett and Garton (2005) maintain that the social construction of knowledge is most effective when one partner is more competent and presents a different point of view, providing for both cognitive conflict and sharing of new knowledge for the less expert partner, who has access to new information within her/his zone of proximal development.

As authors work on their VMCAnalytics, they were enculturated into a community of practice that includes teachers, teacher educators and researchers who contribute to a common knowledge base about the teaching and learning of mathematics. Authors then utilized that knowledge for their practice and research as they learned to use a specific tool of the community, the RUanalytic tool. The actions of the participants of this community mutually affected the others' experiences of meaning. These meanings were reified by the VMCAnalytic that was created, and participation helped members interpret these reifications. Participants occupied different positions in the community. Thus reviewers and authors had different identities in this community, but both contributed towards a common knowledge base as well as utilized that knowledge. The process of learning through participation is meaningful in and of itself and can be considered the most effective form of learning.

The process of revising VMCAnalytics based on feedback is a form of collaborative work which occurs around shared artifacts and which is supported through the medium of technology. Thus, the learning that occurred in this process is, essentially, trialogical in nature. Furthermore, the VMCAnalytic provides a forum for sharing knowledge among students, educators, researchers, and professionals and for mediating their collaborative knowledge advancement. These ideas are central to the theory of trialogical learning. This framework which accounts for how various theories of social learning are involved in the learning phenomena which take place as authors collaborate with others as they revise their VMCAnalytics is demonstrated in the diagram below:

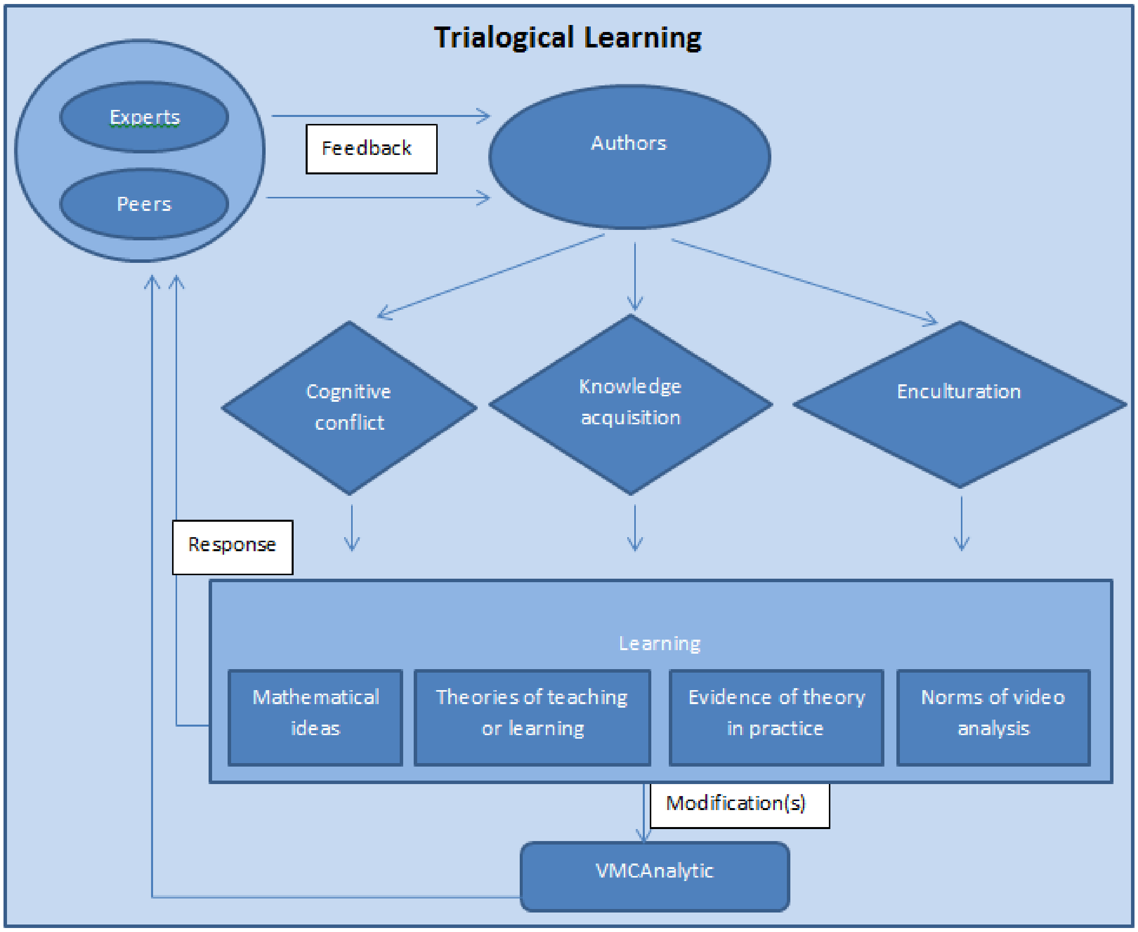

Figure 2.1.1.6. Trialogical Learning

2.1.2 Collaboration

2.1.2.1 What is Collaboration?

Collaboration is a term that is often used by researchers in the context of discussing learning that occurs through social interaction. However, scholars differ in their definitions of collaboration and in their views of what critical elements are necessary for interaction to be considered collaborative.

Damon and Phelps (1989) discussed *peer tutoring* and *peer collaboration* which encourage different types of peer engagement which they evaluate through the properties of equality and mutuality. In *peer tutoring*, children do not have equal status since the tutor has greater control of the information and interaction than the tutee and the level of mutuality varies. In *peer collaboration*, novices with similar levels of competence work together on complex tasks which neither partner can solve alone. Peer collaboration involves high levels of both equality and mutuality since it encourages engagement in which each partner shares ideas and responds to the ideas of the other. Damon and Phelps contended that, based on theoretical assumptions, the different methods of peer education lead to different educational outcomes. Peer tutoring is beneficial in helping participants perfect skills they have already gained while collaborative learning can support the acquisition of novel skills.

Dillenbourg (1999) differentiated between cooperative work and collaborative work. He stated, “In cooperation, partners split the work, solve sub-tasks individually, and then assemble the partial results into the final output. In collaboration, partners do the work ‘together’” (p. 8). Dillenbourg specified four criteria for a *situation* to be considered collaborative. First, there must be symmetry between the members of the collaboration in terms of ability to perform actions. Second, collaborators must be on similar levels in terms of skills, knowledge, and status. Third, collaborators must share the same goals. Last, the members of the collaboration must “work together” through division of labor. Dillenbourg also delineated three criteria for *interactions* to be considered collaborative. He asserted that collaboration must be interactive, synchronous, and open to negotiation. Furthermore, Dillenbourg asserted that several *processes* are specific to collaboration, namely, internalizing concepts used when interacting with others and appropriating, or reinterpreting, one’s own thoughts based on feedback from others.

Teasley and Roschelle (1993) defined collaboration as “a process by which individual negotiate and share meaning relevant to the problem-solving task at hand” (p. 230). Roschelle and Teasley (1995) considered one type of collaboration defined as “a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem” (p. 70). They, too, distinguished between “collaborative” and “cooperative” activity by defining cooperation as a division of labor wherein each individual is responsible for part of the project and collaboration as a joint interaction of members in a mutual attempt to resolve the issue at hand. Although they distinguished between synchronous and asynchronous work, unlike Dillenbourg (1999), they contended that both synchronous as well as asynchronous activity can involve collaboration. Additionally, they described the process of collaboration as involving “periods of individual activity” as well as “periods of conflict in which individual ideas are negotiated with respect to shared work” (p. 77).

Stahl, Koschmann, and Suthers (1995) stated that cooperative learning is “something that takes place individually” since individuals merely “contribute their individual results and present the collection of individual results as their group product” (p. 3). On the other hand, they defined collaborative learning as learning that “occurs socially as the collaborative construction of knowledge” as group members negotiate and share meaning. Participants “remain engaged with a shared task that is constructed and maintained by and for the group as such” (p. 3). Thus, what differentiates collaboration from cooperation is the “negotiation and social sharing of *group meanings*” (p. 3) which is not reducible to individual learning. Since collaboration is a “group process” rather than “an aggregation of individual change” (p. 3), the methodology required for studying collaboration is different than that required for studying cooperation. Rather than using a pre-test, post-test model, studies of collaboration involve analyzing the "utterances, texts, and diagrams that are produced during collaboration" (p. 8) in order to "understand how learning events themselves take place in the interactions between participants" (p. 11). Dillenbourg et al. (1995) agreed that since collaboration involves more than just the sum of the parts, studies of collaborative learning need to examine the group as the unit of analysis and focus on "socially constructed properties of the interaction" in order to construct a "process-oriented account" (p. 189).

Although many scholars differentiated between cooperative and collaborative learning, according to Chinn (2010), many researchers do not clearly distinguish between the two, and indeed, in his article, Chinn stated that he uses the terms interchangeably. In his discussion of cooperative and collaborative learning, Chinn identified several processes that characterize collaborative learning. These include: interdependence among group members, students' attention to the same features of the task, meaningful contribution by all participants, and uptake of information which can include both building upon as well as critiquing the ideas of other.

2.1.2.2 Collaboration as a Lens for the Current Study

This study examines the process of how authors and reviewers engaged with one another as authors revised their VMCAnalytics for publication and how this affected both later interactions and the development of the VMCAnalytic. The interaction between authors and reviewers involved elements of peer tutoring which was described above (Damon & Phelps, 1989). Members of the interaction were involved in editing or suggesting edits for all pieces of the VMCAnalytic, discussing each element rather than being responsible for distinct components. By discussing each element to achieve a mutually agreed upon result, members of the interaction were involved in achieving intersubjectivity by creating shared meaning around the creation of multimedia artifacts, a process that is characteristic of collaboration. However, the process that was examined in this study is not fully collaborative, since it does not fulfill some of the conditions required for true collaborative work as delineated by the extant literature. For example, although reviewers occasionally revised the VMCAnalytic, they more often provided feedback to authors. Thus, symmetry of action was lacking. Similarly, reviewers and authors may not have been perceived as possessing equal status or knowledge, thus such symmetry was lacking as well. However, many features of collaboration were present in the interaction. Members shared the same goals and worked together through interactive relations. Most importantly, reviewers and authors "negotiate[d] and share[d] meaning relevant to the problem-solving task at hand" (Teasley & Roschelle, 1993, p. 230). The process itself that was studied was a group process which was analyzed through the online discourse as well as through the VMCAnalytic which was produced through the collaboration, or the "socially constructed properties of the interaction" (Dillenbourg et al., 1996, p. 189). Although the process was not synchronous, Roschelle and Teasley (1995) asserted that activity does not have to be synchronous in order to be considered collaborative.

Since the study investigates a key feature of collaborative work, namely intersubjective meaning making which was studied through the process of information uptake, the lens of collaborative learning and the theories that build upon it are useful for informing the study. Therefore, literature related to collaboration, is examined next in this review. Additionally, although the word collaboration is defined by many authors as involving equality of participation, this work will refer to the activity of interaction between authors and reviewers as collaborative since they are engaged in the activity of co-constructing knowledge and intersubjective meaning making which is a fundamental aspect of collaboration.

2.1.2.3 Characteristics of Effective Collaboration

Barron (2000) studied characteristics of effective collaboration. She analyzed group-level characteristics of collaborative study groups and the relationship of these characteristics to problem-solving outcomes in order to gain insight into the optimal design of collaborative learning environments. She examined three features of collaborative group engagement: “the mutuality of exchanges, the achievement of joint attentional engagement, …and alignment of group members’ goals for the problem solving process” (p. 403). Barron contends that to build joint understanding, collaborators must work in a coordinated fashion, keeping track of what has been agreed upon and what has been revised, being mindful of the contributions and knowledge gaps of participants, and clarifying ambiguities in conceptions and terminology that are being employed.

Barron’s (2000) study sought to pinpoint the types of interactions that foster and hinder such coordinated collaboration via video-supported interaction analyses of two pairs of high performing sixth-grade students. Her methodology included the coding and quantification of dialogue relevant to the problem at hand and the analysis of “solution-critical” moments. Barron chose to study two groups whose level of success in collaborative learning were starkly different, and she demonstrated how the differences in interaction contributed to the success of one group and the failure of the other one to resolve the problem at hand. She found differences in the way transition points were managed; how possible solutions were articulated; whether and how proposals were repeated; how proposals were accepted, clarified, elaborated, or rejected; the articulation of solutions compared to the recording of these solutions; the repetition of proposed ideas by the speaker or others; reactions to proposed solutions; and missed opportunities for convergence on shared understanding. The interactions of the successful group were coordinated and socially relaxed and were characterized by cooperative collaboration, with participants offering partial solutions and others filling in lacking information and completing and carrying out the original ideas. The successful group exhibited a spirit and protocol of mutuality that allowed all members to contribute and for reciprocity of dialogue to occur. Her study demonstrates that cooperative participation in a community of practice could constitute important venues of learning if participants engage in optimal collaborative practices that include a steady degree of organized goal-oriented work, tolerance, teamwork, and collegiality. In sum, she found that “between-participant interaction ….is a fundamental source of variability in collective accomplishments” (p. 431).

Kreijns et al. (2003) contended that for collaborative learning to succeed, group members must feel that they belong to a community and work toward a common goal. They emphasized the socio-psychological dimension of such learning and claim that existing CSCL contexts fail to afford sufficient means for socializing, leading to the absence of a sufficiently robust group structure to develop a learning community of knowledge building. Community building entails a process of “affiliation, impression formation, and interpersonal attraction" (p. 343), all of which are easier to attain in face-to-face learning environments that provide vision and audition. Computer mediated learning has been described as "unfriendly, task-oriented, and anonymous" (p. 345) and it could even make for unrefined conduct (Sproull & Kiesler, 1986) all of which are caused by a lack of social presence (Short, Williams, & Christi, 1976). But Kreijns et al. cited research that indicates that although CSCL is capable of producing the community building that is a sine qua non of collaborative learning, the CSCL environment necessitates more time for this to occur (Forsyth, 1990; Hobaugh, 1997).

In a similar vein, in her study of online courses, Burge (2008) found four types of peer behavior among collaborative learners required in on-line collaborative knowledge building: participation (providing alternative perspectives); response (providing feedback); affective feedback (complimenting, using other peoples' first names); and focused messaging. Regarding instructor or facilitator behavior, she found that skillful managing of discussions and providing fast feedback and technical help were also useful for successful collaborative learning.

2.1.2.4 Negotiating Shared Meaning

As discussed above, a fundamental feature of collaboration is the construction of shared meaning. Roschelle (1992) studied how two or more people construct shared understanding or "convergence of meaning" (p. 237). To do so, he analyzed five episodes drawn from video of two hour-long collaborative conversational interactions enacted by students using the Envisioning Machine computer software to explore and explain physics problems. He also conducted interviews with the participants in which the students explained their changing conceptions of the problems. Roschelle used conversation analysis to microanalyze the achievement of convergent meaning through conversational interaction and found that the process which leads to mutual conceptual change and new shared meaning among collaborating persons is characterized by the following four features: “(a) the production of a deep-featured situation, in relation to (b) the interplay of physical metaphors, through the constructive use of (c) interactive cycles of conversational turn-taking, constrained by (d) the application of progressively higher standards of evidence for convergence” (p. 235). Throughout his study, Roschelle emphasized the importance of illustrations and computer presentations as social instruments to negotiate shared understanding in collaborative communication.

Roschelle (1992) found that conversational turn-taking structures are central to the negotiation of meaning among scholarly collaborators insofar as they incrementally increase the participants’ collective knowledge and its sophistication. By refining ambiguous, imprecise, figurative and segmented meanings, conversational modes of interaction “construct, monitor and repair shared knowledge” (p. 237). Via recursive turn-taking conventions, the students he studied built on each other’s conceptions, introduced new thoughts into a joint theoretical structure, and repaired disagreements. He concluded that collaborative knowledge construction is accomplished by gradual augmentation through social interaction in a joint activity and that such mutual knowledge-construction through conversational interaction is a more significant feature and stimulant of collaborative activity than Vygotsky’s notion of scaffolding or Piaget’s notion of cognitive conflict.

In a related study, Roschelle and Teasley (1995), attempted to analyze the development of a “joint problem space” (p. 69) by means of shared terminology, environment and activity. Their aim was to determine how collaboration occurs and the supportive role that computers can play in collaborative learning. In their study, Roschelle and Teasley analyzed the interaction between two students who were videoed as they collaborated on solving a physics problem in the Envisioning Machine computer-based environment during three 45 minute sessions. Additional data were collected by conducting interviews with the participants following the sessions. Roschelle and Teasley used features of pragmatics, conversation analysis, and protocol analysis so analyze the data.

Roschelle and Teasley (1995) called the domain of interpersonal activity a “joint problem space” (p. 69) between participants which consists of aims, assessment of the existing status of the problem solving process, cognizance of possible strategies to reach a solution, and shared understanding of the relationship among these knowledge elements. Roschelle and Teasley analyzed the participants’ language and action to understand how they used these tools to build shared understanding, recognize divergences of ideas, and rectify such divergences to achieve joint construction of new knowledge. They found that participants used computer activity to overcome obstacles to and impasses in shared understanding. They also found that use of the computer both invited and constrained participants’ interpretations of shared understanding. Roschelle and Teasley conceived of the study of collaborative learning via the use of computer technology as providing vital input into future designs of computer-supported collaborative learning.

Hmelo, Nagarajan, and Day (2000) also investigated how students construct a joint problem space with the use of computer scaffolding. They found that the way in which students constructed a joint problem space differed between groups of medical students with more and less prior knowledge. While students with more prior knowledge used their prior knowledge to design plans for solving a design task, students with less prior knowledge were less systematic in their planning.

Chinn, O'Donnell, and Jinks (2000) studied patterns of "discourse structures" that characterize peer collaboration and the relationship of the discourse structures to the extent and quality of student learning. They did this by analyzing the overall structure of conversation within groups of fifth graders as they sought to determine the relative merits of conclusions regarding electrical circuits. Chinn et al. studied 105 students who worked in groups of four. The researchers focused on the quality of the discourse structure of argumentation as half of the groups of four, fifth graders were tasked to figure out whether a given set of conclusions were "OK or not OK" and the other half were tasked to state which of those conclusions were the best and the worst as per standards for good conclusions that they were studying. Chinn et al. aimed to find out whether peer group conversation consisted of complex argumentations generated collaboratively, whether the level of argumentation could be linked to student learning outcomes, and how the different task directives influenced the level of discourse structure as students presented evidence to support their arguments.

Chinn et al. (2000) found that some forms of collaborative peer discourse can be considered as discourse of argumentation. Furthermore, characteristics of such argumentation discourse can be used to foretell post-discourse scores on the writing of conclusions. Their quantitative measure of the level of argumentation among group members showed that the quality of argumentation was predictive of the students' ability to write conclusions. They thus found that the structure of peer discussion is linked to the knowledge that students gain from peer collaboration. They determined that more complex argumentation, whether individually formulated or constructed interactively, fostered learning. They further found that the students who were tasked with rating conclusions as the best or worst were far more successful in eliciting complex argumentation than those instructed to state whether the conclusions were OK or not-OK because the former required students to engage in more reflection to distinguish between competing conclusions than did the latter. The students were found to acquire more knowledge when they were obliged to come up with more elaborate reasoning and to rebut their peers' arguments than when a simple and quick answer could suffice. Their quantitative analysis of discourse structure demonstrates that "all explanations are not equal" and that "elaborated," and multiple, rather than single-node explanations, are required to stimulate learning. Their study shows that the analysis of peer discourse structure is highly germane to an understanding of how peers learn from collaborative activities.

Powell (2003) also analyzed students' discourse and, interactions as well as their inscriptions as they collaborated on a mathematical combinatorial problem, "The Taxicab Problem," in an effort to gain insight into their reasoning and mathematical ideas. He also studied how their discourse supported their problem solving.

Powell (2003) analyzed video data and student work generated by four 12th-grade students from a working-class district who worked on a mathematical problem during an after-school problem solving session that lasted for approximately 100 minutes. These students were participants in the longitudinal study conducted by researchers from

Rutgers University that is described in more detail in later sections (e.g. Francisco & Maher, 2005; Maher, 2010). In this session, they worked on a task that was the culmination of a strand of combinatorial tasks that the students had worked on over the course of the study. The problem's mathematical structure was similar to that of other tasks from the strand, inviting the students to deepen and build upon mathematical ideas they had previously constructed. The students worked without a facilitator; however, during the last twenty minutes of the session the students presented their resolution to the researchers and answered questions posed by the researchers. Powell created a transcript from two cameras views which amounted to 1,619 turns of talk. He also analyzed video of follow up interviews and field notes.

Powell (2003) analyzed the data using nine phases of analysis: 1. *Viewing attentively the video data;* 2. *Describing consecutive time intervals;* 3. *Identifying critical events;* 4. *Transcribing the video record;* 5. *Coding synchronously the transcripts, videotapes, and inscriptions in an inductive and deductive manner;* 6. *Writing analytical memoranda;* 7. *Constructing visual representations of codes and categories;* 8. *Constructing a storyline;* and 9. *Composing a narrative.*

Powell (2003) extended Davis' (1996; 1997) framework to study "discursive practices of learners in conversational exchanges or cognitive interlocution" that "guides the inquiry into how learners' discursive exchanges structure their investigation as well as contribute to the mathematical ideas they build" (2003, p. 49). Like Roschelle (1992) who studied turn-taking structures, Powell analyzed his data using a unit of analysis which he called *interlocution*. He used the term interlocution to refer to "a chunk of meaningful conversation" or "the back and forth talk of conversational partners" (p.

46).Hence, he organized the transcript of the video by numbering each “turn of speech” (p. 104).

Powell (2003) found that students used discourse to “structure their own investigation” (p. 103) and engaged in discourse with each other for 77% of the time without interacting with the researchers. The researchers did not direct the investigation; rather, during this time, the students worked to understand the problem, develop strategies for solving the problem, invented algorithms, constructed arguments and justifications, and built isomorphisms using the representation of Pascal’s triangle. Participants developed heuristics for solving the problem, and spent about 18% of their time constructing algorithms to solve the problem, without the researchers present.

Additionally, Powell (2003) found that the students engaged in four types of interlocutory interactions: *evaluative* in which “an interlocutor maintains a non-participatory and an evaluative stance,” *informative* in which “an interlocutor requests or announces factual data,” *interpretive* in which “an interlocutor endeavors to tease out what his or her conversational partner is thinking, wanting to say, expressing, and meaning,” and *negotiatory* in which “an interlocutor engages and negotiates with his or her conversational partner” (p. 174). In particular, Powell found that mathematical ideas emerged from interlocutions that were informative, interpretive, and negotiatory. Further, interlocutions that were interpretive or negotiatory had the potential “for advancing the mathematical understanding of individual learners” (p. 182).

Based on the results of his study, Powell (2003) concluded that students should be afforded time to develop problem-solving heuristics and that ideas should be “reflected on deeply, presented publicly, submitted to challenge, available for negotiation, and subject to modification" since the development of mathematical ideas is "often a protracted, iterative, and recursive phenomenon, occurring over more time that is usually appreciated or acknowledged in practice in classrooms and reports in the literature" (p. 189).

2.1.2.5 Trialogical Learning

Hakkarainen (2008) introduced the idea of a trialogical approach to learning. Trialogical learning, according to Hakkarainen, denotes collaborative work around shared artifacts. The framework explains how learning and professional communities that are supported by collaborative technologies create new knowledge and transform social practices by developing shared epistemic objects through long-term interaction. The framework incorporates the following six features: 1) emphasis on collaborative activity mediated by shared objects, 2) long-term efforts of knowledge advancement, 3) combination of both individual and group activities, 4) knowledge sharing between students, educators, researchers, and professionals, 5) innovation supported by theoretical and practical considerations, and 6) technology support for learning through the mediation of shared artifacts.

Trialogical learning is supported by newly developed collaborative technologies which enable intellectual teamwork in the area of pedagogy, and these technologies are necessary tools for the resolution of complex interdisciplinary issues. But Hakkarainen et al. (2006) argued that technology promotes knowledge creation only through transformed social practices in schools and workplaces since knowledge creation requires "certain kinds of social practices of working with knowledge" (p. 16). The triaglogical approach focuses on the collaborative development of mediating artifacts rather than on monologues within an individual mind (the acquisition approach) or on dialogues between individuals (the participation approach). Hakkaarainen recommended a transformation of the perception of students, teachers and other educational professionals not as mere consumers of knowledge, but also as potential producers of new knowledge and developers of new educational practices. To achieve this goal, Hakkarainen advocated the elimination of boundaries between teachers and other school professionals and between academia and the real world.

2.1.2.6 Uptake Analysis Methodology for Studying Intersubjective Learning

Suthers (2006b) introduced the term, *intersubjective learning.* In this epistemology, learning is a "participatory process" in which knowledge can be "jointly created"; however it "may involve disagreement as well as agreement about shared information" (p. 317). Suthers stated that in order to study intersubjective meaning making, one must study the process itself, or "how people in groups make sense of situations and of each other" (p. 321). According to Suthers, intersubjective meaning making occurs when participants "contribute to a composition of inter-related interpretations" (p. 321).

Suthers (2006a; 2006b) described "eclectic analysis of uptake," a framework for studying intersubjective meaning making by analyzing how participants of a collaborative activity "take up and build on prior contributions" (2006a, p. 115), a concept he terms "uptake." The analysis of information uptake is useful for understanding how the collaborative activity is composed of individuals' activities and representations, or notations, with which they interact and how knowledge is thereby constructed. Suthers used three phases to analyze information uptake. First, he identified instances of artifact modification. Next, he identified the relationship of information uptake to each act. Last, Suthers interpreted the uptake graph using relevant conceptual frameworks to pinpoint instances of knowledge construction.

Suthers (2006a) applied his methodology to data collected for an earlier study (Suthers et al. 2003). Participants were same-gender pairs of university students collaborating through a software environment to examine hypotheses relating to the cause of neurological illness. The software enabled students to collaborate in a synchronous fashion through a chat tool and through a graphical tool in which students posted notes, called an evidence map. Suthers examined data logged by the software of user chat messages and interaction with the evidence map.

In order to analyze activity as a function of its context, Suthers (2006a) used an adaptation of sequential analysis (Sanderson & Fischer, 1994) that accounted for the uptake of information in which the uptake does not necessarily occur immediately following the presentation of the information. In his methodology, Suthers analyzed information uptake in the form of discussion or representational manipulation based on either the participant's own or another's contributions. He then identified phenomena that were exposed by the analysis. Examples of socio-cognitive conflict were identified when participants took up ideas that expressed differences. The phenomena of distributed cognition and knowledge construction were identified when representations were modified in an intersubjective way by more than one individual. Instances where representations made interaction possible were identified as examples of activity theory. Additionally, Suthers looked for instances of representation guidance when conversations were prompted by participants' intention to transform a representation or when participants used representations in order to make their ideas explicit. Using this methodology, Suthers described the intersubjective meaning making activity of several case examples.

Looi, Song, Wen, and Chen (2013) extended Suthers' (2006a; 2006b) paradigm of uptake analysis in their study of how one group of fifth grade students collaboratively constructed a shared artifact in their study of electricity. Looi et al. studied multiple types of uptake in an environment that encompassed verbal, online, and experimental collaborations. Additionally, they identified pivotal interactions that altered the focus of ensuing activities and analyzed how such interactions helped shape the interaction. Specifically, Looi et al. examined the transcripts of approximately four minutes of interaction taken from six video recordings of a 30-minute lesson and their corresponding screenshots and data logs from the software that the students used to create the artifact. Those four minutes were selected to be analyzed in great detail since "interesting interactions happened in [that] segment" (p. 269).

Contributions by participants were coded for *individual utterances, acts of artifact creation and experiments,* or *sets of sequential utterances or acts that form a single interactional move.* After representing the contributions and their codes in a chronological fashion, the researchers identified uptake relationships, both intrasubjective as well as intersubjective, by identifying contributions that built upon previous contributions. After creating an uptake graph, Looi et al. (2013) identified segment boundaries in which activity changed in either a seamless or abrupt fashion. This analysis enabled them to find pivotal contributions, "contribution[s] that shift the direction of subsequent events… through uptake between the pivotal and subsequent contributions."

Looi et al. found that the majority of uptakes were verbal and occurred between multiple participants. They also identified seven pivotal contributions that led to significant changes in the direction of the students' inquiry and found that group inquiry was supported by uptake paths and the construction of shared artifacts and that multiple mediators supported the construction of knowledge.

2.1.2.7 Summary

Collaboration occurs as individuals with similar levels of competence work together on complex tasks which neither partner can solve alone and involves high levels of equality and mutuality between participants. Participants do the work together, with symmetry of action, skill, and status, shared goals, division of labor, interactivity, negotiation, internalization of concepts, and re-interpretation based on feedback. Collaboration is furthermore characterized by interdependence among group members, students' attention to the same features of the task, meaningful contribution by all participants, and uptake of information. Individuals negotiate and share meaning relevant to the problem-solving task at hand. Characteristics of effective collaboration include coordination and mutuality between participants, collaborative discourse, and a common goal. Trialogical learning is collaborative activity which is mediated by a shared object. Uptake analysis is a useful methodology for studying intersubjective meaning making and can be used to understand how participants of a collaborative activity "take up and build on prior contributions" (Suthers, 2006a, p. 115). This methodology identifies instances of artifact modification, the relationship of information uptake to each act of discussion or representational manipulation based on other contributions, and interprets the uptake graph using relevant conceptual frameworks to pinpoint instances of knowledge construction. Pivotal interactions are those that alter the focus of ensuing activities and help shape subsequent interactions.

2.1.2.8 Uniqueness of this Study

The process of collaboration can be used in reference to the social interactions that occur as users develop and refine their VMCAnalytics based on peer and reviewer feedback. However, this study differs from other collaborative studies in the sense that the authors of VMCAnalytics already constructed prior knowledge about teaching and learning as well as knowledge about the video collection. Further, they also made use of certain theories in which to situate their video narratives. Furthermore, VMCAnalytic authors in this study strove for excellence by seeking to deepen and strengthen the communication of their knowledge to others. The authors in this study are categorized as experts or novices, although those classified as novice authors already had some initial experience. The participants were teachers in an M.Ed. program whose VMCAnalytics were chosen to be revised in preparation for publication or completing a master’s project. Already, their VMCAnalytics were rated favorably by outside reviewers as having the potential for publication. Thus, the authors were not true novices working with peers, nor novices working with experts, but rather they were near-experts working with even more knowledgeable others. Hence, the relationship of interviewers or reviewers with authors was not just collaborative, but was additionally characterized by elements of a mentoring relationship. Studying the process of collaborative learning in such a participant group is important in order to understand how advanced students improve and refine their knowledge of the teaching and learning of mathematics as they progress towards achieving greater expertise.

2.2 Supporting Learning with Video

2.2.1 Introduction

2.2.1.1 History

Sherin (2004) surveyed how video has been historically used for teacher training. Video use in teacher education began in the 1960s with its use in microteaching, which is a training technique consisting of teachers reviewing video footage of their own teaching in order to analyze their teaching deficiencies and make improvements until a desired result is achieved. The 1970s saw the inception of interaction analysis, which studies the relationship between teaching techniques and student achievement. Video made this system eminently feasible and hence vastly increased its prevalence in the field of teacher training. In the 1980s, the modeling of expert teaching for novices through videos of lessons taught by veteran teachers became a popular training technique in teacher education. A specific form of expert teacher modeling, case-based pedagogy, utilizes video-based cases to provide novice teachers with rich examples of teaching dilemmas to train them to reflect on problem solving best practices and to expand their professional knowledge base. Hypermedia programs linking video to text and graphics made their appearance in the 1990s and these programs were directly made possible by innovations in computer technology and the capacity to digitize video. Additionally, video has been used to record classroom teaching in order for supervisors to have the capability to focus on segments of videotaped field recordings to illustrate a given point and to serve as the basis for group reflection.

2.2.1.2 Affordances and Constraints of Video

Although video use has become ubiquitous in the professional development of teachers, Sherin (2004) contended that users and producers of video pedagogical resources do not always grasp what it is about video that makes it so valuable in teacher training and hence do not fully exploit the full potential of video use.

Sherin (2004) did note the drawbacks of video for teacher education. These include the passive nature of video observation, the limited classroom view and information captured by video, the inability of video to portray the full range and intricacy of the classroom context, and the fact that video is the product of the videographer's own biased perspective of the overall classroom reality.

Nevertheless, Sherin (2004) posited that three major advantages of video make it highly beneficial in teacher professional development: the fact that video constitutes a lasting documentation, the fact that video can be edited and recombined, and the fact that video makes it possible to design a new set of teaching practices to inculcate pedagogical expertise. The permanence of the video record allows for clarification and an additional perspective as well as for the selection of a specific focus of study. Because video can be collected and recombined it can be collected in video libraries as well as linked electronically to curriculum, teacher reflection and student work. In turn, the permanence and editable nature of video can together engender the emergence of a new set of practices involving what Sherin called an "analytic mind-set." Video affords the luxury of time and hence student activity captured on video can serve as the basis of reflection rather than immediate action. Video also affords the viewing of different pedagogical approaches, which in turns encourages comparisons between alternate teaching styles and strategies. Finally, video lends itself to fine-grained and extended analyses of small segments of classroom happenings, leading to better understanding of student thinking processes. Hence video holds the key to better reflection on and interpretation of classroom practices and interactions.

Sherin (2004) recommended the use of video to record teaching over an extended period of time to develop teachers' professional identities and to provide the basis for teachers' reflection on their own practices. She further advocated the creation of Internet based video networks to serve as the basis of a virtual community of teachers.

Maher (2008) presented the value of video as a means for analyzing how mathematics concepts and reasoning develop in students. She reviewed and offered a justification for incorporating video into the education of math teachers and provides cases of the effective use of video collections for the teaching of pedagogy and professional development. She then described instances of the fruitful use of the massive and significant video collection that she conceived and spearheaded at Rutgers University. Finally, she charted future directions in the use of video for showing how children build new knowledge and how teaching techniques influence student learning.

Additionally, teachers can use videos to analyze their own teaching and to contemplate the quality of their understanding of student reasoning (Maher, 2008). They can consider the efficacy or lack thereof of their actual classroom interventions and improve their techniques, and they can study in detail obstacles to student learning as well as their creativity in problem solving. Maher (2008) reviewed the various ways that video portfolios can be used to these ends, via video "cuts" of critical student learning or teaching events, related written work by students, and notes by teachers and researchers tracing the evolution of a mathematical idea. Video collections make it possible to view consecutive lessons multiple times and they can serve as the basis of individual teacher reflection or group discussions of student learning and pedagogical approaches.

2.2.2 The VMC and RUanalytic Tool

2.2.2.1 The Video Collection

Researchers from Rutgers University, led by Carolyn A. Maher, began a longitudinal study in the working-class Kenilworth district in New Jersey in 1987 (Maher, 2010). The study eventually encompassed about 80 students from three districts in New Jersey, including the urban district of New Brunswick, NJ and the suburban district of Colts Neck, NJ (Francisco & Maher, 2005). A group of Kenilworth students were followed for over twenty-five years, from first grade through post-college, while students from New Brunswick and Colts Neck were followed over the course of several years in elementary and middle school. During this cross-sectional, longitudinal study, students learned mathematics by working on open-ended mathematical tasks. According to Hmelo-Silver et al. (2013),

> An overarching goal of all the studies has been to follow groups of students over time to enable the tracing of how they build mathematical ideas and forms of mathematical reasoning when situated in a learning environment that encouraged thoughtfulness, building meaning of mathematical ideas, collaborating with others, and sharing of ideas in the establishment of justifications for problem solutions (p. 3080).

Class sessions, informal learning sessions, as well as individual and small group interviews were videotaped, and over 4500 hours of video were collected (Agnew, Mills, & Maher, 2010; Hmelo-Silver et al., 2013). These videos comprise the Robert B. Davis Institute for Learning (RBDIL) video collection. The institute has also retained researcher field notes and records of student work.

2.2.2.2 The Video Mosaic Collaborative

The VMC repository was created to enable long-term wide access to the RBDIL video collection (Agnew et al., 2010). Built on the Fedora infrastructure of the RUCore (Rutgers Community Repository), the VMC currently hosts close to 300 videos and clips, enabling researchers, teacher educators, and teachers to study videos of elementary and high school students engaging in tasks across eight content strands which include algebra, counting and combinatorics, fractions and rational numbers, geometry, pre-calculus, calculus, and probability (Hmelo-Silver et al., 2013). The VMC architecture was designed to allow the association of metadata with each clip or video, providing related information such as the title, description, duration, information about the mathematics the students engage in, information about the students and facilitators, and related publications, as well as access to its transcript and any related student work (Agnew et al., 2010). A website was created to provide researchers, teachers, teacher educators, and students with portal access to the resources of the VMC. Its design was based on an analysis of how teachers and researchers work with video resources and allows users to search and access videos from the RBDIL collection and view related video metadata.

2.2.2.3 The RUanalytic Tool

A crucial component of the VMC is the RUanalytic tool (Agnew et al., 2010; Hmelo-Silver et al., 2013). The RUanalytic tool allows users to create multimedia artifacts using the videos from the VMC repository. The web-based RUanalytic tool allows users to find videos from the RBDIL video collection using a built-in search feature, and to then analyze, edit, and annotate video selections. Users also have access to VMC metadata related to the videos they have selected. Completed VMCAnalytics can be published as permanent repository items in RUCore. A VMCAnalytic is composed of sections of video, or events, with accompanying text analyses. The VMCAnalytic is also accompanied by a description outlining its goals or purpose. According to Agnew et al., VMCAnalytics are intended to serve a multitude of purposes, from “structured essays on specific topics… to terminology codes that can be captured… and analyzed” (p. 6). VMCAnalytics can be shared among users, enabling multiple people to participate in the construction of a single VMCAnalytic. Additionally, VMCAnalytics can be created to code and analyze the VMCAnalytics created by others. The RUanalytic tool is intended for use by students, teachers, teacher educators, and researchers. A new commenting feature has also been added to the tool. The new feature allows users to engage in threaded discussions with each other. Discussions can be related to entire VMCAnalytics or, on a finer level, to specific VMCAnalytic events.

2.2.2.4 Using the VMC for Teacher Education

2.2.2.4.1 Effects on Beliefs

Videos and other resources from the VMC are currently being used for research in a plethora of education environments, including graduate courses in mathematics education and learning sciences, in-service teacher intervention programs, and pre-service teacher education classes for elementary, middle, and secondary levels (Hmelo-Silver et al., 2013). Courses and interventions were implemented in various settings, with some participants meeting face-to-face to watch and discuss videos and others participating in hybrid or online course formats. Researchers have studied how the beliefs of pre-service and in-service teachers are affected by interventions which include the study of video from the VMC (Hmelo-Silver, Maher, Agnew, Palius, & Derry, 2010;

Maher, Landis, & Palius, 2010; Maher, Palius, & Mueller, 2010; Palius & Maher, 2011; Schmeelk & Sigley, 2012).

In a preliminary investigation, Hmelo-Silver, Maher, Agnew, Palius, and Derry (2010) studied pre-service and in-teacher beliefs and how they are affected by studying videos from the VMC. Participants in their study were drawn from three pre-service classes and one in-service intervention. After working on mathematical tasks, participants studied videos of children working on the same problems. Hmelo-Silver et al. found that the interventions effected changes on teacher beliefs regarding both beliefs about student learning and the effects of instruction.

In a more in-depth analysis, Maher, Landis, and Palius (2010) studied changes in in-service teacher beliefs effected by an intervention intended to support teachers' attention to student reasoning. The intervention was composed of a series of three cycles of professional development workshops which extended over the course of a school year. Twenty middle school teachers of both regular education and special education from two diverse New Jersey schools participated in the study. In each cycle, teachers worked together in small groups to solve tasks from the counting strand of the longitudinal study and discussed their solutions with each other. Teachers then watched videos from the VMC of students engaging in those tasks and discussed the types of reasoning used by students in the videos. They then prepared to implement the tasks with their own students, discussing how to present the task, pair the students, and respond to students who need help without guiding them directly. After implementing the tasks in their own classrooms, teachers analyzed student work together at the next workshop session. Questionnaires to assess pre- and in-service teachers' beliefs about children's learning and the effect of instruction were administered before and after implementing the interventions. Maher et al. observed changes over the course of the intervention in the beliefs of in-service teachers regarding how students learn mathematics and how their learning was influenced by teachers. On average, teachers' beliefs improved in terms of alignment with current beliefs about mathematical education for about 64% of items tested, declined for 4%, and remained stable for about 32% of items studied. No differences were observed between regular and special education teachers. The results suggest that changes in beliefs may be effected by teachers' engagement with mathematical tasks and their subsequent study of students engaging in those same tasks utilizing similar problem solving strategies. This activity encourages teachers to confront their own beliefs as they reflect on the forms of reasoning naturally used by children as they work on problem solving tasks.

In a similar study focusing on an in-service teacher population, Maher, Palius, and Mueller (2010) investigated the effects of a video intervention on the beliefs of pre-service teachers. The intervention was conducted for pre-service elementary school teachers and extended through a little more than half of a semester of a teacher education course. The participants were drawn from an elementary math methods course. Participants answered questions regarding their beliefs before and after the course. A comparison group completed the same beliefs questionnaire but did not participate in video study during their intervention. The experimental intervention aimed to help teachers recognize and make sense of student reasoning and representations. Towards this end, teachers engaged in tasks and then watched videos of students engaging with those same tasks. The videos were selected to illustrate the process through which students attain mathematical understanding and focused on content from the fraction and counting strands. Teachers then discussed their observations with each other. Maher et al. found that the beliefs of pre-service teachers were also changed over the course of the intervention, specifically in relation to how students learn. Their change about student learning was significantly different than the beliefs of the comparison group in this regard. However, although there was change in regard to how pre-service teachers believed student learning is affected by teachers, beliefs about teaching did not change. In fact, these beliefs were comparable to the beliefs evidenced by the comparison group.

According to Palius and Maher (2011), the difference in belief changes between those reported in Maher, Palius, and Mueller regarding pre-service teachers and those reported in Maher, Landis, Palius (2010) regarding in-service teachers may be attributed to the fact that in-service teachers implemented the task with their own students and were able to observe the effects of changes in their practice.

2.2.2.4.2 Effects on Recognizing Student Reasoning

In addition to studying changes in beliefs, researchers have also studied the effects of video interventions on teachers' ability to recognize student reasoning. In their study of 22 graduate students from two online Critical Thinking and Reasoning courses, Palius and Maher (2013) compared pre-and post-test measures from a video-based assessment of teachers' ability to recognize student reasoning. The assessment required teachers to describe the reasoning expressed by children in a video and to discuss whether the reasoning is convincing and why. Responses were coded to evaluate the completeness of the arguments presented. Completeness was judged by whether or not all of the necessary components for a complete argument were present. In the online course, teachers met once in person at the beginning of the course, to be introduced to how Cuisenaire rods were used in the intervention so that they could become accustomed to using rods and rod trains as units for which fraction relationships were modeled. Teachers then studied videos from the fractions strand on the VMC in which students built conceptual understanding of fractions using the rods before being introduced formally to fraction concepts in school. Teachers also reviewed research literature related to those videos and discussed their thoughts with each other online. After the intervention, 11 out of 13 students or 84.6% who had not identified all the components of a complete upper and lower bound argument in the pre-test exhibited growth by identifying more components of a complete argument in the post-test. In regard to identifying the features of an argument by cases, 5 out of 6 students, or 83.3% exhibited growth on the post-test.

Similarly, Maher, Palius, Maher, Hmelo-Silver, & Sigley (2014) studied the effects of a video-based intervention on 127 K-5 and secondary pre-service teachers and K-8 in-service teachers. A similarly composed comparison group of 50 pre- and in-service teachers participated in classes that did not involve the video-based intervention. Participants from the experimental group who engaged in the video-based intervention worked on problems from the counting strand and watched videos from the VMC relating to students solving the same problems. Maher et al. investigated participants' ability to recognize student reasoning based on their pre- and post-test responses, this time regarding arguments created by students to justify their solutions to a problem from the counting strand. Assessments were coded to measure the completeness of the arguments described. Their analysis showed no significant differences between the comparison and experimental groups on the pre-test. However, whereas 4% of comparison group participants exhibited growth on the post-test, 52% of K-8 in-service teachers, 38% of pre-service secondary teachers, and 17% of pre-service K-5 teachers improved in their ability to recognize student reasoning on the post-test.

2.2.2.5 Using the RUanalytic Tool for Teacher Education

2.2.2.5.1 Factors that Influence Artifact Design and Artifacts as a Means of Assessment

In addition to studying the effects of interventions utilizing VMC resources on student beliefs and students' ability to recognize children's reasoning, researchers have also investigated the use of the RUanalytic tool in teacher education. Hmelo-Silver et al. (2013) argued that the RUanalytic tool can support learning through design as users plan and evaluate their VMCAnalytics. In their study of the use of the VMCAnalytic and the factors that influence their conceptions, Hmelo-Silver et al. analyzed 27 VMCAnalytics created by researchers and students from 4 graduate classes. Participants in a hybrid Introduction to Mathematics Education course first studied videos from the VMC and subsequently built VMCAnalytics from videos drawn from the combinatorics strand in which children built towers selecting from two colors of Unifix cubes. Participants from an online Critical Thinking and Reasoning course studied and created VMCAnalytics from videos drawn from the fractions strand, while students from a Mathematics Education Practicum course worked individually or in pairs to create VMCAnalytics which were not related to course content. Participating students from a Design-Based Research course analyzed one video clip as part of the course requirement and created VMCAnalytics with few stated guidelines. VMCAnalytics were rated for their clarity, coherence, and mathematical and learning sciences depth.

Hmelo-Silver et al. (2013) found that students with stronger mathematics education backgrounds created VMCAnalytics with greater mathematical depth. Students from the Critical Thinking and Reasoning course showed the most depth with regard to learning sciences. Researchers and Practicum students showed the most coherence and clarity in their VMCAnalytics, with coherence and clarity being highly correlated. Analysis of the focus of the VMCAnalytics revealed that students from different classes emphasized different ideas in their VMCAnalytics, related to a large degree to the goals of the various courses for which they were created. Thus, students from the Design-Based Research class did not focus on mathematical content, while 90% of students from the Introduction to Mathematics Education course focused on mathematical ideas, with 30% focusing on specific mathematical content. Many students from the Mathematics Education course simultaneously focused on ideas related to the learning sciences such as collaboration, communication, and argumentation. From the Critical Thinking and Reasoning course, 80% of students' VMCAnalytics focused on specific mathematical content, with significant emphasis on learning sciences ideas as well, and all three Practicum students focused on mathematical content, with two simultaneously including learning sciences ideas. Hmelo-Silver et al. assert that VMCAnalytics enable researchers and teachers to gain insight into students' thinking and analyses, enabling a possible means of formatively assessing students' learning. Additionally, Hmelo-Silver et al. suggest that the VMCAnalytic can be used by researchers to trace learning trajectories and to track the development of ideas and the effects of collaboration and teacher questioning on student learning.

In a related study, Hmelo-Silver, Maher, Palius, Sigley, and Alston (2014) analyzed 63 VMCAnalytics created by graduate students from 7 classes, examining how well students identified evidence for their claims, the effect of course content and instruction on VMCAnalytic quality, and the extent to which VMCAnalytics could be used to assess students' knowledge of children's reasoning. The parameters outlined for VMCAnalytic requirements varied between the different courses in terms of videos to be used and length of the expected VMCAnalytic in time and number of events. For example, students from one semester of the Introduction to Mathematics Education course described above were instructed to use specific videos from the counting strand, but students from two subsequent semesters were allowed to use videos of their choice. Participants from the Critical Thinking and Reasoning course described above were expected to create VMCAnalytics from the videos of the fractions strand which they had watched as part of their coursework. Students from one semester of the Design-Based Research course referenced above were given limited instruction and were allowed to choose any video they wanted, but students from a subsequent semester were instructed to use videos from a given subset of videos and were guided in terms of the number of events to include and VMCAnalytic length. In addition, VMCAnalytics created by students from an Early Algebraic Learning course were studied. In this course, students studied videos from the algebra strand, and although not required to limit themselves to using those videos, many students constructed their VMCAnalytics from those or related videos.

VMCAnalytics were graded using a comprehensive rubric including measures for clarity, coherence, mathematics and learning sciences depth, and event relevance. Hmelo-

Silver et al. (2014) found that students with more preparation and guidance, as well as those directed to use a specified limited number of videos as their basis, created VMCAnalytics which received better scores than those who were not as well directed. Additionally, students who helped create the rubric created VMCAnalytics which were more focused. The rubric used for rating VMCAnalytics reliably differentiated between different students, with varying levels of correlation between different metrics. For example, the measure of clips connecting meaningfully to the VMCAnalytic was highly correlated with the metrics for coherence and clarity as well as with event relevance. Similarly, overall VMCAnalytic clarity was highly correlated with event relevance. These results suggest that VMCAnalytic clarity is tied to the selection of meaningful events. In contrast, the number of events in the VMCAnalytic was not strongly correlated to any other measure. Hmelo-Silver et al. suggest that the VMCAnalytic can provide a method of assessing students' thinking about children's mathematical learning since it serves to make their thinking visible through the artifacts they create.

2.2.3 Other Video Collections and Video Analysis Tools

2.2.3.1 Using Other Video for Teacher Education

As noted, many studies have been conducted related to the use of video in teacher education. Selected research related to the effects of video analysis on teacher education will be discussed below.

2.2.3.1.1 Effect of Video Analysis Ability on Student Performance

Kersting, Givvin, Sotelo, and Stigler (2010) studied the impact of teachers' ability to analyze video of students learning fractions on their own students' performance in fraction learning. Over 220 fifth to seventh grade teachers completed an analysis of classroom video, a 15-item multiple choice Mathematics Knowledge for Teaching (MKT)-based assessment that gauged their fraction content knowledge, and a questionnaire about their background regarding education and experience. Teachers watched online video clips taken from 11 fractions lessons in fifth and sixth grade classrooms which focused on core fraction concepts and highlighted teacher assistance, student misconceptions, or whole class discussion. Teacher were asked to “discuss how the teacher and the student(s) in the clip interacted around the mathematical content” (p. 174), and responses were rated for *mathematical content*, *student thinking, suggestions for improvement*, and *depth of interpretation.* Student learning for 19 of the teachers was assessed using a 15 item multiple-choice pre- and post-test administered before and after instruction.

Kersting et al. (2010) found that scores of teachers’ video analyses and content knowledge were significantly correlated, with the subscale of mathematical content most highly correlated with and the strongest predictor of mathematical content knowledge. The scales for student thinking and suggestions for improvement did not account for any additional variance in the content knowledge assessment, and depth of interpretation accounted for very little variance. Only one subscale, suggestions for improvement, which teachers were not explicitly requested to comment on, was significantly correlated with student learning, with observations for some clips found to be more predictive than for others. The content knowledge assessment was not correlated at all with student learning. Kersting et al. concluded that knowledge that affects instruction, such as that which motivates a teacher to suggest improvements, affects student learning. Content knowledge and analyses of mathematical content alone were not sufficient to improve student outcomes; rather only teachers whose knowledge affected their instruction as indicated by their suggestions for improvement, experienced enhanced student learning outcomes. Additionally, some clips promoted better explanations and student outcomes, so Kersting et al. recommend studying the varying affordances of different clips.

2.2.3.1.2 Indexing Video for Classroom Use

InVideo is a tool which can automatically transcribe the audio portion of video and analyze and index video content based on both its audio and visual components. The tool enables users to search the content of the video and then add comments or tags. Additionally, InVideo can be used to divide large videos into shorter segments. In a study investigating the benefits of using the InVideo technology to support student learning, Wang, Maher, Cheng and Kelly (2017) found that using InVideo to index video and create shorter video clips both enhanced student participation and increased students' ability to understand and remember the content of the videos. In their study across twenty-four sections of a Masters Cybersecurity program, students submitted almost seven times as many responses to video viewing as compared to responses of students from the previous semester. Additionally, both project and final grades of participating students averaged higher than grades of students in corresponding courses from the previous semester.

2.2.3.1.3 Methods of Video Study

Zhang, Lundeberg, Koehler, and Eberhardt (2011) developed a professional development program to compare the affordances of three methods of video study: studying published video, video of one's own classroom, and video of a colleague's classroom. Twenty-six teachers, from elementary, middle, and high schools, from eighteen schools participated in the program. Data were collected in the form of teacher surveys, reports, interviews, posters, and reflective group discussions, videos of group discussions, and facilitator notes. The program began with teachers first using a PBL approach to develop their own science content knowledge. They then watched two video cases of students working on science activities in small groups or discussing the activities as the whole class. Teachers used a PBL approach to solve facilitator-constructed problems centered on the video cases, analyzing the video cases, and then constructing a plan for studying their own classroom practice as teacher researchers. By analyzing published videos, teachers were introduced to video cases and discourse relating to video study. Teachers then designed science units for use in their own classrooms, were taught how to video their classrooms and create video cases from their video. They then implemented the units in their classrooms over the course of the year, created video cases and studied their own video as well as the video of others in the program.

Zhang et al. (2011) coded the data collected from the various sources to determine the affordances of various types of video, separately analyzing the affordances gained by watching video and discussing video. The researchers found that published video afforded teachers a model for using PBL to analyze video cases and a means for reflecting on their own practice by comparing it to the video cases. Challenges of studying published video included content or grade-level mismatches with teacher experience and lack of context. Analyses of teachers' own videos provided opportunities for critical and descriptive individual reflection and comparative collaborative reflection. It also offered teachers new perspectives on their practice. Additionally, it enabled them to study their students' collaboration skills. Technical challenges with creating videos and discomfort with being videoed were the main challenges of using teacher videos. Watching the videos of colleagues offered teachers insight into others' practice, enabling comparative reflection. Challenges included technical difficulties, too much focus on student work instead of the teacher, and unnatural behavior caused by discomfort with being video taped. Based on their findings, Zhang et al. (2011) recommend providing context for published video and selecting video based on relevant content and grade level. Additionally, they suggest that teachers should reflect, both individually as well as collaboratively, and use structured discourse like PBL to guide discussion.

2.2.3.1.4 Learning from Video Cases

Derry, Hmelo-Silver, Nagarajan, Chernobilsky, & Beitzel (2006) designed a pre-service teacher course model called STELLAR (Socio-Technical Environment for Learning and Learning-Activity Research) in order to facilitate the transfer of skills learned in classes to practice by enabling students to envision their plans for practice while learning course material and to foster an approach to teaching that incorporates reflection, self-directed learning, and collaboration. Derry et al. created eSTEP (Elementary and Secondary Teacher Education Project) courses using the STELLAR course development system which were implemented in learning sciences courses for teachers at Rutgers and UW-Madison. Materials produced for these courses included an online library of video cases highlighting pedagogical techniques, an online resource, Knowledge Web (KWeb), with learning sciences information, and an online PBL site to support lesson design with discussion forums and shared whiteboards. Students in the courses solved three or four problems which required to students to redesign or design lessons based on video cases.

In a quasi-experimental design, courses were implemented in teacher education programs by sophomores, juniors, and seniors. Course success was evaluated using pre- and post-tests in which students analyzed a video case and answered questions related to the video. These tests evaluated students' ability to analyze videos of classroom learning and interviews of students and were scored using a rubric designed to measure understanding of student cognition. Using exploratory regression, Derry et al. (2006) found that student ratings of online tools were correlated with student learning as measured by the pre- and post-tests and students' perceptions of their own learning was correlated with their ratings of the online tools. Data was also qualitatively analyzed using CORDTRA (Chronologically-oriented Representations of Discourse and Tool-related Activity) diagrams which synthesized records of students' use of tools with their online discussion. Derry et al. found that students' use of video evolved over time, with students attending to more detail over the course of the semester. Additionally, students initially did not successfully complete the problem, and required facilitator scaffolding in order to succeed in later tasks. In a comparison study of 101 eSTEP students and 126 comparison students, Derry et al. found that eSTEP students performed significantly better than traditional students.

In a related study, Beitzel and Derry (2004) used STELLAR tools to study how contrasting video cases affects learning. Beitzel and Derry randomly assigned 150 students to one of three groups, a group who contrasted video cases before reading a related assignment, a group who contrasted video cases after reading a related assignment, and a group who just read the assignment and took notes, but did not contrast video cases. Student learning was measured with assessments aimed to test participants' recall of information and their ability to apply that information to new contexts. Beitzel and Derry found that contrasting videos before reading had a negative effect on student learning, while contrasting video cases after reading had a positive effect. Results were significant at the .001 level, with an effect size of 1.63 for recall of terms, and .96 for recall of gist; however, results for students' transfer ability were not significant between the two cases. Similarly Nagrajan (2006) found that contrasting videos is a cognitively demanding task but that scaffolding can reduce cognitive load.

2.2.3.1.5 Studying Teachers' Own and Colleagues' Video

Borko, Jacobs, Eiteljorg, & Pittman (2008) implemented a professional development lesson study model in a project called "Supporting the Transition from Arithmetic to Algebraic Reasoning" (STAAR). In their work with middle school teachers, Borko et al. strove to create an atmosphere in which teachers felt comfortable sharing and discussing videos taken in their own classrooms. Their model was centered around *a problem-solving cycle*. During each cycle, teachers first worked on a mathematical task, attending to the mathematical ideas behind the task, thinking about how students may approach the problem, and planning for implementing it in their own classrooms. Then the teachers implemented the task in their own classrooms, video-taping each teacher as well as one group of students in each class. Teachers then regrouped to discuss the implementation and watch videos highlighting teacher questioning, student thinking, or interesting student strategies.

Borko et al. (2008) implemented three problem-solving cycles over the course of two years with eight participating teachers the first year and ten teachers the second year, seven of whom had participated the previous year. The workshops were video taped using multiple cameras and coded to describe the kinds of conversations that teachers had regarding video. They also analyzed researcher field notes, reflections, and transcribed facilitator and teacher interviews. Borko et al. found that teachers spent twice as long discussing videos during the last cycle than they did during the first (154 minutes during the last cycle as compared with 74 minutes during the first cycle), concentrating more of their discussion on the video itself rather than in "setting up the discussion" (p. 426). Additionally, teachers spent more time discussing mathematical content and student learning during the third cycle. In contrast, during the first cycle, teacher spent more time discussing student difficulties and less time talking about what the student may have been thinking**,** indicating that teachers became more comfortable discussing pedagogical issues and the validity of student responses.

Similarly, Sherin and Han (2004) explored the effects of a *video club* model of professional development. In a video club, members meet to view and discuss video excerpts of footage taken in their own classrooms. In their intervention, four middle school mathematics teachers from one school participated in the video club for about 40 minutes once a month for seven months. The researcher videoed one teacher's class prior to each meetings, with two teachers agreeing to have their classes videoed. Then the researcher and teacher together selected an excerpt of about six minutes, typically from whole class discussions, to review with the group. Sherin acted as the facilitator for the sessions while Han observed. Sherin attempted to elicit teacher observations about the video and asked them to explain students' ideas.

Sherin and Han (2004) studied what video events teachers attended to and how they understood student thinking. To do this, they analyzed the content and form of teachers' discussions. Transcripts of each meeting were segmented by topic and coded to reflect their content as *pedagogy, student conceptions*, *classroom discourse, mathematics,* or *other.* The researchers calculated how much time was spent on each of the categories and how many segments were initiated by the researcher or by a teacher. Two topics, student conceptions and pedagogy, which were discussed most often, were examined to determine how they were discussed and whether they were discussed differently over time. Sherin and Han found that teachers' conversations shifted from focusing more on pedagogical issues to focusing more on student conceptions and that they required less prompting from the facilitator in order to do so. They also found that teachers' conversations became more complex and analytical about students' thinking over time and that rather than merely restating what a student said, teachers more often tried to understand the meaning behind the students' statements and synthesized their ideas. Additionally, over time, conversations about pedagogy centered more around relating pedagogy to student thinking and instead of discussing general pedagogical issues without relating it to student thinking. Interestingly, they did not note a difference between teachers who analyzed videos of their own classrooms and those who did not.

2.2.3.2 Using Other Video Analysis Tools for Teacher Education

Various tools besides the RUanalytic tool have been created for video analysis and annotation and have been studied by researchers at other universities. Research related to the effects of tool usage, which generally supports the idea that using video annotation tools improves students' and teachers' ability to analyze video, will be discussed next.

2.2.3.2.1 Advantages of Using a Video Annotation Tool for Authors

Zahn, Pea, Hesse, & Rosen (2010) studied the learning advantages achieved by users of a video analysis tool compared with users who analyzed video without the support of a tool. Specifically, Zahn et al. investigated the impact of using the Diver tool in a design task. Diver, the Digital Interactive Video Exploration and Reflection system, is a desktop video-editing tool that enables users to create Dives, collections of video clips, which can be re-ordered and annotated (Pea et al., 2004). Diver also allows users to highlight and select just a part of each frame of video. The selected clips can be uploaded and stored on a remote system called WebDiver. Once uploaded to WebDiver, users can view and share Dives and can comment on each other's Dives.

Zahn et al. (2010) compared students who used the video editing tool with students who instead used a tool for video playback in conjunction with a separate word processor. Students in the group who used just video playback and word processing could not edit videos, but could watch the video in the playback tool and create comments in the word processor. Zahn et al. analyzed the features of the tool that promote learning and the socio-cognitive mechanisms that might account for such learning. In their study, Zahn et al. presented 48, 1st-3rd semester psychology students, with no special expertise in history with a task of designing an historical presentation for a museum. Students worked in pairs, using an historic newsreel video of the Berlin blockade as the basis of their presentations. Twelve of the pairs used the WebDiver tool for video editing while twelve used Apple QuickTime, a tool for video playback, in conjunction with WordPad as a word processor. Members of each group had comparable backgrounds and similar levels of relevant historical knowledge as revealed by t-test analysis of pre-questionnaires related to subjects' educational, computer, and media production background and pre-tests of subjects' content knowledge. Students were tasked with critically analyzing the video, reading related texts, and designing a web page to publish the video with their comments. In this way, it was anticipated that students would creatively use video to portray their ideas.

Zahn et al. (2010) studied learning gains through pre- and post-tests, through analysis of the artifacts created, and through video data of dyad collaboration captured using webcams and screen recorders. Post-tests measured content knowledge and video analysis and reflection skills using multiple-choice questions and a transfer task involving video. All the videos of dyad collaboration were coded and analyzed, but only select video data were transcribed. Zahn et al. considered dyads as their unit of analysis since the design artifacts they created were products of the group. Zahn et al. found that students who used the video editing tool revealed moderately better content knowledge and video analysis skills on the post-test than those who used the video playback and word processor tools. Additionally, students who worked with the video-editing tool created video clips that were more precise. In addition to their quantitative analysis of students' content knowledge, video analysis skills, and final multimedia products, Zahn et al. also analyzed the video data qualitatively, asserting that the video editing tool acted as a mediating instrument in enabling participants to find common ground and work together more efficiently. Their study results indicate that the use of tools created for video editing and annotation, especially in a collaborative environment, can be a good means of promoting students' ability to analyze video data.

2.2.3.2.2 Effects on Analysis

In-Service Teachers

Focus on student learning. In a study designed to investigate the effects of using another video editing tool in teacher education, Hauge and Norenes (2009) examined the use of VideoPaper in their work with five, secondary mathematics teachers over the course of a six-month school-based intervention. VideoPaper is a desktop application that allows users to select portions of video and create associated captions, text, and image annotations. VideoPaper artifacts can be exported to the web and hyperlinks can be created to play the selected clips. The intervention aimed to improve the methodology used by the teachers in their mathematics instruction. Hauge and Norenes collaborated with two teachers in planning a lesson emphasizing group-based inquiry that could be videotaped for the VideoPapers. After videotaping the lesson, all five teachers participated in selecting clips to use for the VideoPapers and contributed their interpretations of the events. The researchers then built two VideoPaper artifacts based on the teachers' input and the teachers discussed the products in two successive workshops. Based on interviews with teachers, videos of classroom lessons, and findings from teacher workshops dedicated to analyzing their practice, Hauge and Norenes found that VideoPaper focused teachers' discussion around student learning and encouraged teachers to be more open to discussing their practices, although teachers resisted planning collective practices to be used in the future. Additionally, Hauge and Norenes found that VideoPaper played an integral role in mediated teachers' activities by making it possible to share their experiences and generate fresh outlooks on learning and teaching.

In contrast to the methodology employed by Hauge and Norenes (2009) in which researchers created video artifacts for teachers to discuss, albeit with significant teacher input, Sherin and van Es (2002; 2005; 2006) designed studies in which teachers themselves created the video artifacts. Sherin and van Es studied the effects of the use of another tool, VAST (Video Analysis Support Tool), on how pre-service and in-service teachers analyzed videos of their practice. Developed at Northwestern University, VAST is a desktop application that allows users to select pieces of video and associate comments with them. VAST provides special tabs for entering information about student thinking, teacher’s roles, discourse, and mathematics or science content. Each tab contains text areas for users to enter specific types of information about the video, such as what they notice, evidence, interpretations, or questions. A transcript of the video is displayed alongside the video, as well as lesson artifacts. VAST is primarily designed to allow users to write specific types of analytical comments about sections of video. It provides scaffolding prompts for teachers to use in analyzing video. In one study cited by Rich and Hannafin (2008), Sherin and van Es (2006) analyzed the use of VAST by in-service teachers participating in video clubs. Meeting monthly or bi-monthly during the academic year, teachers used VAST to analyze videos of their teaching. Teachers who participated in this study changed in the ways that they analyzed video by focusing less on teacher actions and more on the ways in which their teaching affected student learning.

Pre-Service Teachers

Focus on student learning. Sherin and van Es (2002; 2005) also conducted a grounded, iterative study of six pre-service secondary mathematics and science teachers to investigate the effects of studying video excerpts using VAST on student teachers' ability to notice videoed classroom events. In video-taped sessions lasting three hours, pre-service teachers used VAST to analyze videos of their own teaching and the teaching of others. Prospective teachers also completed pre- and post-assessments in the form of essays discussing videos of their own lessons. The essays were coded to reflect the events that teachers noted, the evidence they gave, and whether they described, evaluated, or interpreted the events in the video. Coding results were compared with the results from a comparison group of six pre-service teachers who did not use VAST to analyze video. Sherin and van Es noted changes in what participants noticed and how they interpreted events. In contrast with the pre-assessment essays in which pre-service teachers mainly related events as they occurred chronologically, in post-assessment essays created after using VAST pre-service teachers primarily focused their analysis on noteworthy events. Additionally, in pre-assessment essays student teachers primarily evaluated how they may have done things differently, whereas in post-assessment essays student teachers concentrated more on interpreting the events and analyzing the effects of their pedagogy on learning, basing their interpretations more strongly on evidence from the videos.

Aspects of the video annotation process that benefit analysis. Preston, Campbell, Ginsburg, Sommer, and Moretti (2005) also analyzed how interaction with videos through using a tool affects the way student teachers attend to video. In their study, Preston et al. analyzed how using the VITAL tool (Video Interactions for Teaching and Learning) can benefit student teachers in building meaning and learning to attend to video data. Developed at Columbia University, VITAL is a web-based application that allows users to create video clips with associated hyperlinks which can be imbedded as references in text essays. VITAL was created for use in Herbert Ginsburg's graduate course on young children's mathematical thinking (Preston et al., 2005). VITAL provides uses with access to a library of videos, a tool for viewing video that allows users to create and annotate clips, and an area for writing essays with embedded links. When the link in an essay is clicked, the related clip opens in a new window and can be played. Essays published in VITAL can be shared and read by others. Additionally, VITAL supports *video lessons*, which are used by students to watch video interviews with children and assess the interviewer's methods and the interviewee's responses when the video pauses.

In their study, graduate students in a class focusing on young children's mathematical thinking created essays in the VITAL environment for their final projects (Preston et al., 2005). Students created videos of themselves leading a mathematics activity with a child and subsequently conducting an interview with the child. The students then analyzed the video in VITAL. Based on student interviews, Preston et al. found that 66% of students felt that analyzing and selecting video helped them focus on video content, 77% of students found that naming their clips helped them do so, and 73% of students felt that watching videos with the goal of using clips in an essay improved their ability to attend to video. Preston et al. also coded eight essays for each of eight students created over the course of the semester. Results showed that students used fewer clips in their essays over time, though students cited the difficulty of creating clips as a motivation for their reduction of clip inclusion. Preston et al., though, believe that the process of creating more clips early on in the semester aided students in developing habits of closely observing video evidence.

Purposes of the artifacts. In their study of another video annotation tool, VideoTraces, Saxena and Stevens (2007) also analyzed how the use of a tool supported teachers in analyzing student learning. VideoTraces is a desktop application which allows users to highlight portions of video and attach voice comments to the selected segments. VideoTraces enables multiple users to annotate the same video and provides a threaded discussion capacity to enable users to discuss each other's comments. Saxens and Stevens studied 73 video traces created by seven participants including pre-service teachers, in-service teachers, a supervisor, and researchers. Participants created traces from videos of their own teaching and collaborated with each other by discussing and building on each other's traces. The traces were transcribed and analyzed, revealing that users created traces to analyze and hypothesize about teacher practices and about student work. Additionally, traces were used as "cases" which participants used to discuss learning and teaching.

Effect of instruction and practice on analysis. Using a different measure of teacher ability to examine video, Prusak, Dye, Graham, and Graser (2010) studied how student teachers analyze video by investigating their ability to code video reliably. In their study, Prusak et al. analyzed the coding reliability of forty-nine elementary physical education student teachers who analyzed video using StudioCode, a tool that allows users to apply codes and comments to video. Multiple users can apply codes or comment to the same video. Students from two physical education course sections received training regarding teacher competencies related to physical education by watching videos of teachers exhibiting the competencies and through live modeling of the competencies. The students then used StudioCode to code a video of a lesson given by an expert physical education instructor using codes related to the competencies they had studied. Their codes were compared with the instructors' independent coding results. Students re-coded the video up to three times if they did not achieve 80% agreement, receiving feedback after each attempt. Student teachers then videoed the last of the four lessons which they taught over the course of the semester and coded it using StudioCode. Only 29 videos were usable due to various technical issues. Fifteen coded segments were then randomly selected from twenty randomly selected videos and were checked to determine how accurately codes were applied. Videos were not checked to ensure that codes were applied to all possible relevant instances.

Prusak et al. (2010) found that when coding video of expert teachers, student teachers only achieved a reliability of 49% for the first round of coding and an average of 63% reliability for the third round when comparing their coding to that of the two course instructors who achieved a high level of inter-rater reliability. Student teachers achieved a high reliability of 91% when coding their own video, but this reliability figure was calculated differently than the reliability figure reflecting student accuracy compared to the instructors. Reliability for student coding of their own teaching was calculated to reflect the percentage of codes applied correctly as opposed to incorrectly instead of accounting for the percentage of all possible codes which were applied correctly. Therefore, the reliability numbers for student coding of expert videos and student coding of their own videos are not directly comparable since the reliability calculation for the coding of the expert video was more sensitive to factors unrelated to understanding of competencies. These included applying a single code to a group of segments as a whole instead of assigning the same code to each segment individually. The reliability calculation was also affected by the counting of an incorrectly applied code as two deductions since the correct code was not applied and a code was applied incorrectly. Thus, Prusak et al. concluded that the results of the study are inconclusive with regard to student ability to code their own teaching versus their ability to code expert teaching. However, Prusak did find that coding of expert video was more difficult for students than initially anticipated by instructors. Additionally, since students did improve over their iterations of coding the expert video, Prusak et al. assert that video coding is teachable. Furthermore, since students from one class outperformed students of the other, Prusak et al. believe that differences in instruction affect students' ability to code reliably.

2.2.3.2.3 Effects on Reflection

In-Service Teachers

In addition to exploring how use of video annotation tools affects users' ability to analyze video, researchers have also considered the effects of tool usage on teachers' reflection on practice. In one study, Wright (2008) investigated how video analysis using MediaNotes affected the reflections of five novice elementary school teachers and their ability to critique their teaching and identify what could be improved. MediaNotes, developed at Brigham Young University, is a desktop application that allows users to segment video and name and annotate clips. Users can also apply predefined tags to video, enabling them to associate clips with a lens used to frame analysis. Wright compared teachers' reflections before and after engaging in reflection using MediaTools. Before each of three interventions, each teacher identified a skill he or she wished to improve, videotaped the implementation of a lesson incorporating that skill, and subsequently wrote a reflection paper critiquing the lesson and identifying further areas of improvement. Each teacher then used MediaNotes to write analytic comments related to the video of his or her lesson. The teachers then met with the school principal to discuss the lesson, sharing both their written reflections and video analysis comments. In addition to collecting the written reflections and video analyses, Wright conducted audio-taped interviews with the teachers and principal, observed the teachers the first time they used MediaNotes and during their consultations with the principal, administered a survey, and conducted a focus group interview at the end of the study.

Wright (2008) analyzed the data sources thematically, finding that teachers' reflections as portrayed by their comments in MediaNotes showed better analyses of their teaching than was displayed by their prior written reflections. Wright found that video enhanced reflection by providing added perspectives and allowing the teacher to remember more about what occurred in the classroom. Factors of the intervention that were identified as critical in promoting reflection included providing teachers with a set time, structured method, and tool for reflection, providing teachers with a rationale for engaging in reflection, and support for their reflection process.

Tripp and Rich (2012) studied seven teachers who also used MediaNotes for reflection purposes. Each teacher video-recorded four lessons and analyzed them using MediaNotes, tagging it with codes centered around a selected theme. Teachers then shared their clips with each other and discussed their comments, giving each other feedback about the lessons. These discussions were recorded and transcribed. Additionally, after the four cycles were complete, teachers were interviewed. Tripp and Rich coded the data and identified four main relevant themes, *recognizing the need to change, brainstorming ideas for change, implementing the ideas, and evaluating changes* *that were implemented*. They found that video can be useful in effecting change in teachers' practice by enabling them to recognize the need for change and to focus on important features of their teaching. Additionally, teachers felt responsible to implement their peers' suggestions, and reported gratification when they were able to view their progress in subsequent videos.

Pre-Service Teachers

In another study related to the use of MediaNotes for reflection, Tripp and Graham (2009) analyzed how utilization of MediaNotes affected the reflections of one student teacher who taught middle and high school classes. Tripp and Graham analyzed three recorded post-teaching consultations with a supervisor in which teachers engaged in reflection. One consultation was conducted in a traditional fashion and two employed the use of MediaNotes, in which the student and supervisor reviewed clips of the student's teaching and her comments on the clips. Interviews were conducted and recorded with both the student teacher as well as the faculty member coach. The researchers also analyzed the comments created in MediaNotes and coded all the data to capture relevant themes. Tripp and Graham found that the use of MediaNotes promoted the active involvement of the student teacher in the reflection process, allowing her to better prepare for the consultations by watching the video and collaborate more actively with her supervisor by enabling her to comment more on her own teaching in addition to hearing feedback from her supervisor. The student also felt that video was beneficial in enabling her to remember more about her teaching and to back her conversations with her supervisor with evidence.

In another study of how pre-service teachers' reflections were aided through using a tool for video annotation, Bryan and Recesso (2006) studied the use of VAT by pre-service secondary science teachers for reflecting on their teaching practices. Created at the University of Georgia, VAT, a Video Analysis Tool, is a web-based application that allows users to upload videos, select segments of video, and write associated comments for each segment. VAT's live capture feature allows users to stream video from the classroom to a remote server, negating the need for teachers to upload the video afterwards. The VAT software focuses users' analyses by providing frameworks for analysis. Within VAT, users can select features defined by a framework that apply to the video clip. Users can share their videos and annotations with others, multiple users can annotate the same video, and users can then compare the comments created by different users. VAT has been used and studied primarily by teachers analyzing their own practice in the domains of social studies and science. Seven students participated in Bryan and Recesso's study, which ran over the course of fifteen weeks. Before beginning student teaching, students wrote about their beliefs relating to teaching and learning science. During the course of student teaching, students videoed and analyzed at least one session using the VAT tool. The researcher determined the framework within which students analyzed their video and asked students to identify instances of their practice that either aligned or did not align with their beliefs. Students were then asked to identify clips that portrayed the most alignment with their beliefs and the ones that contradicted their beliefs most strongly, discussing why the selected clips were chosen. They then identified ways in which they could better align their practices with their beliefs. Bryan and Recesso found that VAT helped prospective teachers recognize disparities between their beliefs and their practices and confront the complexities of teaching. These findings were supported by a related study conducted by Rich, Recesso, Allexsaht-Snider, and Hannafin (2007). They studied 27 pre-service elementary teachers who created their own literature-based frameworks for analyzing the alignment of their practices to their beliefs. They, too, found that VAT supported pre-service teachers in identifying disparities between their beliefs and their teaching and to improve their practice based on their findings.

Shepherd and Hannafin (2008) also studied the effect of tool usage on pre-service teachers' reflections, specifically in how the creation of e-portfolios, including the usage of VAT for video analysis, affected the reflections of three pre-service social studies teachers. As part of the study, three interventions cycles were implemented in which prospective teachers videoed and analyzed at least one student teaching session per cycle using VAT to include in their e-portfolio. Students wrote comments to explain their actions and note instances where they promoted engagement, using hyperlinks in their e-portfolios to link to the video clips they created. The course instructor and participants were interviewed and audio-recorded at the end of each cycle to understand how the cycles were implemented and to identify reasons for inclusion of artifacts in the e-portfolios and motivations for their analyses. Interviews were transcribed and then coded and analyzed together with the e-portfolios artifacts. The data indicated that video analysis using VAT helped students identify student engagement and reflect on their teaching success from a different perspective. Additionally, video analysis helped teachers to notice events they had not noticed previously, back their claims with evidence, and construct different perspectives about what happened in their classrooms than what they originally perceived. Tool usage was reported to help teachers focus on their practice from various perspectives. However, teachers did not indicate willingness to continue using the tool in practice since they did not perceive that the tool was widely used by practicing teachers.

In another study cited by Rich and Hannafin (2008) that examined both pre-service teacher reflection and use of a video tool for providing supervisor feedback, Miller and Carney (2007) investigated how VideoTraces can support supervisors in providing feedback to student teachers. In their study, three pre-service elementary teachers video-taped two of their own lessons. Supervisors, teachers, and faculty members provided feedback using the VideoTrace tool. Miller and Carney reported that use of the tool helped student teachers reflect on their own teaching, but feedback provided to students varied, indicating that the tool may not be a substitute for in-person supervision and assessment.

2.2.4 Summary

Studies related to the use of videos from the VMC to support teacher education have found changes in beliefs of in-service teachers regarding student learning and the effect of teacher instruction on student learning as well as changes in the beliefs of pre-service teachers regarding student learning. They have also found an improvement of both in-services and pre-service teachers' ability to recognize reasoning. Studies which used the RUanalytic tool as a means of assessing student learning found that course goals affect VMCAnalytic content and strengths and that more direction and limiting the number of videos to work from positively affect VMCAnalytic quality. They also found that the rubric used for scoring VMCAnalytics reliably differentiated between VMCAnalytics. Studies of using other video cases to support teacher education found that studying video cases improved teachers' ability to analyze student learning and that teachers' ability to analyze video of students learning fractions correlated with their own students' performance in fraction learning. The use of video annotation tools in teacher education improved the ability of in-service and pre-service teachers to attend to video and their ability to focus on significant classroom events, the effect of teaching on learning, and student learning. Additionally, in-service and pre-service teachers improved in their ability to reflect and back claims about practice, focus on important features of teaching, and confront disparities between beliefs and practice.

2.2.5 Areas in Need of Further Research

Pea (1999, 2006) urged researchers to employ new electronic methods of publishing research which enable them to link supporting video data to published work in order to make their work more accessible to practitioners. Additionally, he urged scholars to use video as data with accompanying text analyses so that scholars can comment on each other's commentaries in context. Using video as a support to text supports *guided noticing*, an activity whereby an author guides the reader to pay attention to something specific, Pea theorized that guided noticing can help people achieve common ground and support them in understanding one another by establishing shared attention on a common object. Pea suggested that video should not only be used to support teacher learning, but also as "a new form of scientific dialog" (Pea, 2006, p.1370) by enabling researchers to collaborate through shared video. According to Pea, current video analysis tools support individual use of video editing capabilities, but few address the need for researchers to collaboratively analyze video data. Thus, the VMCAnalytic tool and its new commenting feature fills the need for supporting published work with video data and for enabling researchers to collaborate through the mediation of shared video.

According to Rich and Hannafin (2008), there are few rigorous studies related to tool-assisted video analysis since "[r]esearchers have just begun to examine the effects of video annotation tools on teacher practice or student learning" (p. 64). Although the sample sizes employed by many of the studies discussed herein are small, the available research does reveal value in utilizing video and video annotation tools for teacher education and research. Hence there is a need for more thorough scholarship on video annotation tools to understand how they can best be exploited to improve teacher education and research. As described in previous sections, the extant research on the use of tools for analyzing video has mainly focused on the utility of tools in supporting teachers' ability to attend to video and to teacher reflection. Studies related to the use of the RUanalytic tool have centered on exploring how the tool is used, elements which contribute towards the VMCAnalytic product, and how the tool can be used to assess student learning. Research has not yet been conducted to explore how the collaborative analysis of video can support learning about mathematics teaching and learning and how collaboration during artifact design may contribute towards improved video analysis. This is likely due to the fact that there are few tools that support the collaborative analysis of video and therefore "it is rare for collaborators working at different sites to conduct joint analysis of shared video records" (Pea et al., 2008, p. 355).

This study analyzes the phenomenon of "computer-supported collaborative video analysis" (Pea et al., 2008, p. 353) in which participants engage with the newly developed collaboration feature of the RUanalytic tool. It investigates how authors revise

VMCAnalytics based on feedback from reviewers, how authors and reviewers make sense of each other's ideas, and how they negotiate meaning among themselves. It explores how their initial ideas change through discussing them with others and how dialogue between and among group members affects the development of the VMCAnalytic. It traces how the ideas of each group member contribute towards the final product. This study affords deeper insight into the ways in which computer-supported collaborative video analysis is enacted and addresses the need for research in this area.

2.3 Research Questions

In order to understand how computer-supported collaborative video analysis is enacted, the study was guided by the following research questions:

1. How do authors engage with reviewers or peers through the process of multimedia artifact development and revision?
2. How do users take up the ideas of others as reflected by their online or face to face discourse as well as by their modification of multimedia artifacts?
3. How do VMCAnalytics evolve as users take up ideas of others?
4. How do users with different goals, backgrounds, or expertise levels differ in their interaction and uptake processes?

With these questions guiding the study, the analysis examines the kinds of discourse used by authors, interviewers, and reviewers as they discussed multimedia artifact revision and how discourse affected subsequent discourse and the development of multimedia artifacts. It also explores how different users engage in these processes in different ways.

CHAPTER 3 METHODOLOGY

In order to answer the research questions, this study was designed as a qualitative descriptive case study (Suthersb, 2006b). Qualitative studies are valuable for understanding the unfolding of a phenomenon in detail in its natural setting (Creswell, 2006). Since this study intended to gain a detailed understanding of how VMCAnalytics are developed and revised based on the feedback of reviewers or peers, a qualitative methodology was appropriate for analyzing the process in its natural context. Descriptive studies are appropriate for "understanding authentic practice through case studies" and for uncovering "patterns in the data" (Suthers, 2006b, p. 329). Since this study aimed to uncover patterns of collaboration and uptake, a descriptive analysis was suitable. Furthermore, because this study was not constrained by specific theoretical assumptions, a descriptive methodology was particularly appropriate (Suthers, 2006b). In addition, an iterative comparative approach was taken to analyze the data in order to ascertain whether or not patterns present in some interactions were missing in others and what the differences in outcomes were (Suthers, 2006b). The study was executed as a case study (Yin, 2003). The case was defined as the process of interaction during the creation or revision stage of VMCAnalytics of six authors and their reviewers or interviewers. Small groups were used to study the uptake process since researchers have proposed that small groups are the most suitable contexts for studying intersubjective meaning making (Stahl, 2006; Suthers, 2006b).

3.1 Environment: The RUanalytic Tool

The functionality of the RUanalytic tool is outlined in section 2.2.2.3 above. In this section, the commenting tool and history features will be described in more detail along with screenshots of relevant views of the tool.

Figure 1 presents a view of an open VMCAnalytic in the RUanalytic tool designer. The “Discuss” button circled in red opens a screen for entering comments that are relevant to the entire VMCAnalytic. The “Discuss” icon circled in blue is used to open an identical screen for entering comments; however, the comments entered on this screen are related to a single event.

Thus, there is a separate screen for entering and viewing comments for the VMCAnalytic as a whole as well as a separate screen for entering comments for each individual event.

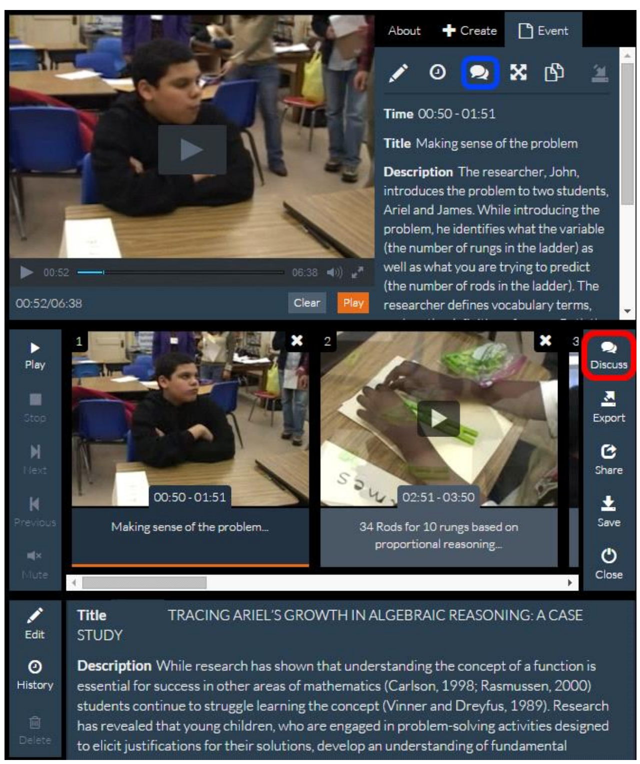

Figure 3.4.1. A VMCAnalytic open in the RUanalytic tool workspace.

Figure 3.4.1 presents a full view of the RUanalytic tool screen. The “Alerts” icon circled in red in the lower left corner appears when new comments have been posted.

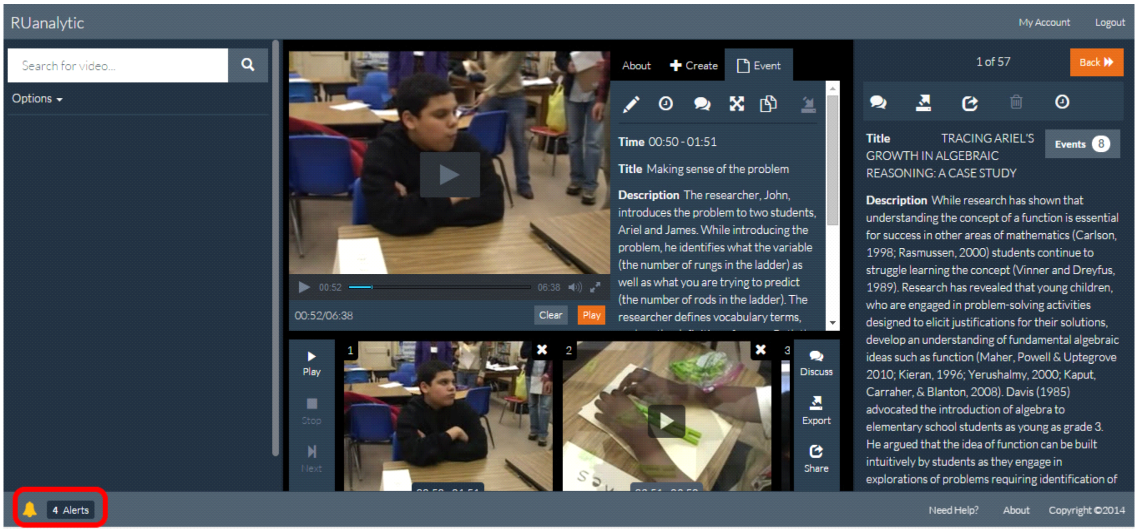

Figure 3.4.2. A full view of the RUanalytic workspace.

Figure 3.4.2 displays a view of the comments screen. Comments are structured as threaded discussions organized by topics. Each topic is composed of a title and initial comment. The initial comment can have multiple reply comments associated with it, and, likewise, each reply comment can have multiple replies linked to it. Thus, users can create a comment for a new topic or reply to any previously created comment. Each comment posted displays a timestamp of when it was created as well as the name of the user who created it.

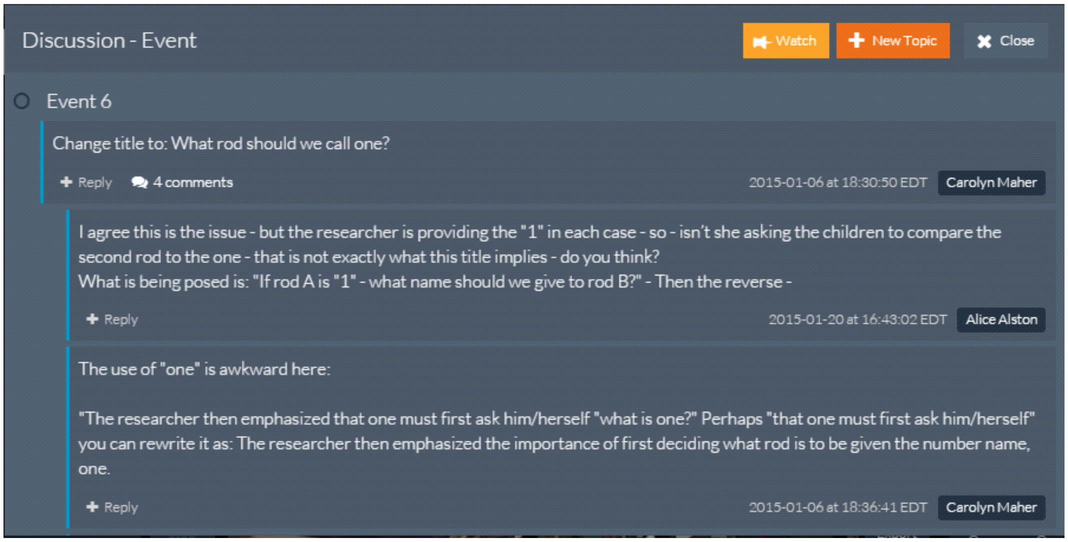

Figure 3.4.3. The comments screen.

Figure 4 displays a partial view of the history of a VMCAnalytic event. The overall description, as well as each event, maintains a version history. The version history for the overall VMCAnalytic preserves the title, description, name of the user who created the version, and a timestamp when the version was saved. The version history for each event contains the starting and ending time for the event video, title, and description of the event, as well as the name user who updated it and the time that it was saved.

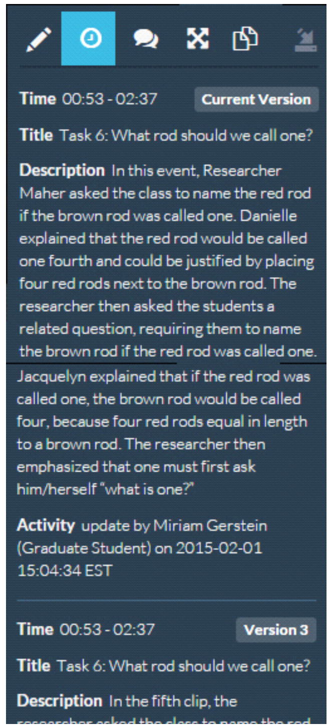

Figure 3.4.4. Revision history.

3.2 Participants

VMCAnalytics can be created for a variety of purposes. Authors create VMCAnalytics as tools for professional development or teaching, as supports for scholarly or dissertation research, or to fulfill course or program requirements. This study examines the creation and revision process of VMCAnalytics created for multiple purposes. Authors who created VMCAnalytics as teaching tools, for scholarly research, for dissertations, as well as to satisfy a course or program requirement are represented by the study. The study members comprise a group that is varied in skill level and includes two subjects who are novices and four subjects who are experts. Novices are defined as users who are less familiar with the VMC collection and RUanalytic tool and had never created an analytic which is close to publication or published before the beginning of the study. Experts are defined as users with more familiarity with the collection and tool who published at least one analytic or who created at least one VMCAnalytic which was close to publication prior to the start of the study. Novices are typically students pursuing a Master’s degree, while experts are usually students pursuing a Ph.D. degree or who have completed a Ph.D. degree, and thus, expertise can be classified in that way as well. The subjects have been selected as a typical case sample of VMCAnalytic users who create analytics or are interested in having their VMCAnalytics reviewed in preparation for publication.

3.3 Data Collection

The data for this study were culled from the records obtained from RUanalytic tool, records of email communication between authors and reviewers that often included the text of the VMCAnalytic in a Word document attachment, and video data. The rationale for using these data sources is provided in the following section. One participant was interviewed and videoed as he created the initial version of his VMCAnalytic. The others created initial versions of their VMCAnalytics individually. All the subjects then engaged in discourse with one or more reviewers. Reviewers had extensive knowledge of the video collection and of the best practices of VMCAnalytic creation. Reviewers provided feedback related to the VMCAnalytics using the commenting feature of the RUanalytic tool or via email and Word document attachments. Records of the interactions available from tool, email, Word documents, and video data were analyzed thereafter. Additionally, each revision of the VMCAnalytic, available via the VMCAnalytic history feature and through the record of Word document attachments, was examined as well. Following the revision process, all authors answered a brief questionnaire related to their background, goals of the VMCAnalytic, and feeling about the experience. Select participants were interviewed as necessary in order to provide a more comprehensive understanding of their responses to the questionnaire or in order to gain a better understanding of any unusual patterns of activity that were uncovered by the analysis.

3.4 Data Sources and Validity

This study used multiple sources of data to triangulate the data and ensure the validity of the results (Creswell, 2006). These sources of data included the RUanalytic tool collaboration records, email correspondence, Word document attachments, VMCAnalytic history, interview video data, questionnaire responses, and follow-up interview data. These sources of data ensure that the evidence was supported in multiple ways. As an additional means to achieve reliability, findings are reported using thick descriptions (Creswell, 2006). Member checks were also employed to verify interpretations made by the study.

Online records of participant interaction were used as an important source of data. Participants created an initial version of their VMCAnalytics and then invited reviewers to offer their comments. Reviewers and authors discussed the VMCAnalytics throughout the VMCAnalytic revision process. Since each comment that is created in the RUanalytic tool is time stamped by the tool, comments were organized sequentially. All comments created by reviewers and authors were examined to understand the nature of their interactions as well as to identify information uptake.

The second data source was comprised of email correspondence created by participants. Since the RUanalytic tool only informs users of updates to VMCAnalytics through the user interface itself and does not provide external methods of alert, it was expected that users may inform each other of changes and comments via email. Users also wished to communicate via emails for other reasons as well. Therefore, these emails also included actual VMCAnalytic text, transcripts, or comments either as part of the email body or as attachments. Thus, any emails and attached documents related to the development of the VMCAnalytic were also used as a source of data for analysis. However, although reviewers occasionally edited the actual text of attached Word documents and authors subsequently accepted those changes, these edits by reviewers were not included as data for the study unless there was additional discourse related to those edits which evidenced information uptake.

VMCAnalytic history served as the third source of data. The RUanalytic tool maintains version history which reflects each change that is made to the VMCAnalytic. This history was analyzed in conjunction with all records of interaction in order to identify how information uptake impacts artifact revision.

Video records of the VMCAnalytic creation process were used as the fourth source of data. One participant created VMCAnalytics at the Rutgers University global environment for network innovation (GENI) lab where a high-speed internet connection is available. This user created VMCAnalytics from a full-length video and was interviewed as he created his VMCAnalytic. The video data that was collected was transcribed and analyzed to examine the way in which this user initially developed his VMCAnalytic.

A fifth source of data was drawn from the participants' responses to a questionnaire relating to their background, goals, and feedback about using the collaborative feature of the tool. These responses were used to classify VMCAnalytics by author background and intended goal. Feedback related to use of the tool was also used to confirm evidence of uptake uncovered by analysis of the other data sources. See the appendix for the list of questions that were included on the questionnaire.

Follow-up interview data was used as the last source of data. Interviews were conducted with participants whose questionnaire answers were incomplete, unclear or undetailed, or whose discourse, creation, or revision process revealed an unusual pattern. Thus, interview data was used to augment the other data sources to create a more comprehensive understanding of the revision process.

3.5 Data Analysis

To answer the research questions, the data were analyzed in multiple steps. First, for each subject, the VMCAnalytic history, RUanalytic commenting history, and email history along with accompanying attachments were organized in sequential order. Next, major cycles of review and modification were identified to help guide the analysis. The process of review began when each subject created a VMCAnalytic and submitted it to reviewers for feedback. Then, during each cycle, reviewers submitted comments via the RUanalytic tool, email, and/or Word document attachments. Each cycle was completed once the author responded to the feedback and submitted the VMCAnalytic for further review. In some cases, there was no evidence of the author soliciting feedback on his or her changes. In those cases, cycles of review were determined by noting clusters of dates when reviewers posted comments, subsequent replies to those comments, and changes to the VMCAnalytic in response to the comments.

Next, the comments created in each cycle were organized alongside their accompanying responses. Then, in order to trace VMCAnalytic history, the version histories were compared for the VMCAnalytic as they appeared at the beginning and end of each cycle. Differences between the versions were noted and then linked with corresponding comments. Thus, discourse was connected with related discourse as well as with related VMCAnalytic modifications. Finally, a narrative was composed to explain the process of VMCAnalytic review and modification for each cycle of review.

The data were then organized into a chart listing each comment, the subject of the comment from the VMCAnalytic or prior comment, and the response to the comment. This chart was used as a modified uptake graph in order to visualize the connections between discourse statements and artifact modification. The uptake chart listed the date, user, and content of each comment. Related discourse and artifact modification were then listed in the chart alongside each comment. This chart proved to be a powerful means of visualizing how information was taken up by users as evidenced by discourse or artifact modification, and the unit of analysis thus consisted of each comment, its associated VMCAnalytic reference or prior comment, and the subsequent related responses of both discourse and artifact modification. The uptake chart created in the analysis for the study was then expanded to include the codes used to analyze the data. The uptake graph considered "uptake relations that are evidenced by the observable dependence of an act on others or their products." (Suthers, 2006b, p. 331) and traced how users "did something" with previously expressed information by the observable acts of either posting a message or modifying the VMCAnalytic.

The data were then analyzed to gain understanding of how each VMCAnalytic evolved. In order to do so, the first and last version of each VMCAnalytic was scored using the rubric detailed by Hmelo-Silver et al. (2014). These scores were used to determine the quality of the final VMCAnalytic and the amount of progress made from the initial version to the final version which was determined by the difference between the initial and final scores of the VMCAnalytic Then, VMCAnalytic outcomes were coded as either high or low quality. VMCAnalytics were coded as high quality if the final VMCAnalytic product was of high quality or if significant progress was made from the first to the final version. VMCAnalytics were coded as low quality if little improvement was made to the VMCAnalytic quality and the final version was not of high quality.

Next, in order to identify which comments led to significant improvement or high quality products, comments were coded by the impact they had on the development of the VMCAnalytic. The coding was verified by two independent researchers. The impact of a comment was coded as *None* when an author did not implement any changes to the VMCAnalytic related to the reviewer's comment. The impact was coded as *Minor* when an author implemented changes which affected just one or two sentences and when those changes did not affect the entire meaning of those sentences. The code *Intermediate* was used when changes were made in more than two sentences or when the changes affected the entire meaning of a sentence. The code *Major* marked instances when changes were made in more than one event, when a single event was completely overhauled, or when several paragraphs of the overall description were changed. The code *Critical* was applied when changes were made in most of the events or when the focus of the VMCAnalytic was redefined.

Examples of how these codes were applied are exhibited in the table below.

Comment	**Before**	**After**	**Impact**	**Explanation**
Include role of	Event did	Event was not	None	There was no

girls with Meredith	not include a explain the role of the girls that appeared with Meredith at the overhead projector	updated. Author responded that it was not necessary to explain their role in that event since their role was already explained		change made to the VMCAnalytic as a result of this comment.
Clarify which claim is referred to	Alan supports this claim by making a claim of his own, namely that you can divide the distance on the number line	Alan supports the original claim made by mathematicians by making a claim of his own, namely that you can divide the distance on the number line between 0 and 1 into very small	Minor	The change that was made only affected one sentence and did not entirely change the intent of the sentence.

	between 0 and 1 into very small parts, even into zillionths.	parts, even into zillionths.		
Use "fraction" instead of "real number"	…it is always possible to find another real number that lies between any two real numbers…	…it is always possible to find another fraction that lies between any two fractions…	Minor	The change that was made only affected one sentence and did not entirely change the intent of the sentence.
Description of analytic too broad	In this analytic, students in fourth grade are exploring fraction ideas.	In this VMCAnalytic, fourth grade students are arguing about whether or not infinitely many fractions can be	Intermediate	Although this change only affected one sentence, it changed its meaning significantly by including a

		placed between 0 and 1 on the number line.		more detailed description of the VMCAnalytic.
The big idea in this event is Michelle who successfully articulates that there are 8 "sides" - three on the front – three on the back – and the top and bottom. Then she counts the 6 square units that are on the two ends to arrive at 30 square units of	Event description did not include a reference to Michelle's idea.	Added: "Michelle is using the rod model and counting the open faces showing in the model. Michelle says that, 'Okay. The length is 3. So it's 3 times 8 so that's another 6. 30. Okay, is that right? 8 plus 8 because there's 8 sides showing. There's 1, 2, 3, 4, 5, 6 , 7, 8, so that's 24. 25, 26,	Intermediate	Several sentences were added to the event description and the event length was altered.

area – show this – describe it in your event description – and then stop.		27, 28, 29, 30." Cut the event video immediately following Michelle's statement.		
Situate the events within the context of the larger longitudinal study, include the grade level and topic	No context given	Added context of longitudinal study, grade level, and topic, noted the students participating at the "feature table"	Major	Several paragraphs were added to the overall description.
Partition third event, describe in more detail, note representations used	Event was long and needed more details	Event was drastically improved – video described in more detail and representations	Major	The entire event description was overhauled.

		used by students explained in greater depth		
Events seven and eight “offer very little” – consider removing		The events were removed	Major	Affected entire events, affected more than one event.
Frame analysis with theoretical basis	Lacking theoretical framework	Added theoretical framework and tied events to it	Critical	Affected several paragraphs of the overall description as well as every event description.
If you could directly connect the behaviors cited in the Description to	Event descriptions did not explain how they showcased	Updated the overall description and seven out of eight event descriptions.	Critical	Affected the overall description and the majority of the event

the specific events, it would be even more powerful.	the various TDMs.			descriptions.

Table 3.8.1. Classification of Comments based on Impact.

A complete description of all critical comments can be found in section 4.7.3.2 - Critical Comments.

In order to understand how users engaged with others, comments, email history, and revision changes were then coded to reflect the nature and location of the discourse and the subsequent uptake. The nature of the discourse was coded in two ways. First, each comment was coded to reflect the aspect of quality that it was targeting, such as the accuracy or coherence of the VMCAnalytic. Second, each comment was coded to reflect the type of learning that the user may have engaged in when considering the comment.

The following codes were used to categorize the aspect of quality that the comment targeted: *Accuracy, Citations, Clarity, Coherence, Connections, Context, and Event Length*. The code *Accuracy* was used when the comment was related to backing claims with evidence accurately or using correct mathematical or theoretical terms. The code *Citations* was used when the comment was related to the citation of literature. The code *Clarity* was applied when the comment was related to the clarity and consistency of the language of the VMCAnalytic's descriptions or titles. The code *Coherence* marked comments related to the focus of the description or the connection of events to the VMCAnalytic's purpose. The code *Connections* was used when a comment was related to the connection of events to each other. The code *Context* was applied when a comment directed the author to provide more context either for the VMCAnalytic as a whole or for a specific event. The code *Event length* was used for comments which related to the length of events. Examples of these codes are exhibited in the table below.

Category	**Example**	**Explanation**
Accuracy	Use “fraction” instead of “real number”	Related to using correct mathematical terms
Citations	Reference Charlene’s dissertation	Related to citing literature
Clarity	Define counter claim	Related to clarity of language
Coherence	Explicitly point out to viewers what to attend to in the video	Related to the focus of the description and its connection to the purpose
Context	Situate analytic	Related to the

	in longitudinal study	need to provide context
Event length	Let event run longer	Related to event length

Table 3.8.2. Classification of Comments based on Category.

Next, each comment was coded to reflect the type of learning that the user may have engaged in when considering the comment. Thus, comments were coded as *Math* when they were related to the underlying mathematics described by the VMCAnalytic. Comments were coded as *Theory* when they related to the underlying theories of learning or teaching highlighted by the VMCAnalytic. The code *Practice* was used for comments that discussed how theories of learning or teaching were evidenced in practice. *Norms* was used to code for comments that referenced the norms of video analysis and VMCAnalytic authorship. Examples of how these codes were applied are demonstrated in the table below.

Learning Category	**Example**	**Explanation**
Math	Use wording "segment of the number line between 0 and 1" instead of	Related to description of underlying mathematics

	“number line labeled from0 to 1”	
Theory	“You can't assume folks know the meaning of terms - "experiential"?...It's OK to put references at end but folks may not have read Lesh. Just say what the categories that will be illustrated are.”	Related to theoretical framework of the VMCAnalytic
Practice	Erik’s claim is not a counter claim	Related to how a theory is evidenced in practice.
Norms	Your title should indicate age of students and topic	Related to the norms of VMCAnalytic authorship

Table 3.8.3. Classification of Comments based on Learning Category.

Additional examples of these codes and how they were applied are noted in section 4.7.3.3 - Discourse and Artifact Modification as Evidence of Learning.

Next, the location of the source of each comment was noted. When a comment was submitted via email, the location was coded as *Email.* When the comment was posted in the RUanalyitc tool, the location was coded as *Tool.* When comments were added to a Word document, either in the document itself or in the comments section, those comments were coded as *Word Comments.* When there was evidence of comments made in phone conversations, those referenced comments were coded as *Phone.*

Next, uptake was coded to reflect the extent to which users took up reviewers' comments. Uptake was coded as *Discussed* when the author discussed the comment with the reviewer before implementing any changes. Uptake was coded as *Explained* when the author clarified why he/she would not be taking up the comment and did not make any changes to the VMCAnalytic as a result of the comment. Uptake was coded as *Full* when the author fully implemented the suggested change and as *Partial* when the comment was only partially taken up. The code *Later* was applied when a comment was not immediately acted upon but was taken up during a later cycle of review. Last, the code *None* marked those comments which were not taken up at all. Applications of these codes are described at length in section 4.7.2 - Uptake.

When there was no uptake, the comments were coded to categorize the clarity of the comments themselves. Thus, comments were coded as *Unclear* when it was unclear to the coders what was meant by the comment. Comments were coded as *Ambiguous* in cases the coders were able to eventually identify what was meant by the comment, but only with some difficulty since the intent of the comments were not easily discernable.

Last, comments were coded as *Clear* when the intent of the comment was readily apparent to the coders. Applications of these codes are described at length in section 4.7.2 - Uptake.

The coding scheme was developed and refined as the data were analyzed using a grounded theory approach to reflect any additional themes identified in the data which were not dealt with by the initial set of codes.

Once the uptake charts and coding were completed, the data were imported into SQL Server so that reports could be run to create tables and charts to assist the researcher in identifying and visualizing any themes that existed in the data. In order to understand how discourse and uptake compared across participant types and goals, the data from each participant was analyzed separately and compared. The tables and charts were used to uncover patterns of discourse and uptake that occurred with participants of different backgrounds and with different goals.

Questionnaire responses and relevant portions of follow-up interview responses were used to understand the author's backgrounds and goals. This information was useful in understanding how users with different backgrounds, goals, and levels of expertise varied in their engagement with interviewers or reviewers

Member checks were used to verify the information gleaned from the comment, email, and revision histories to ensure the accuracy of the analysis. Thus, in case of any ambiguity, this researcher corroborated her understanding of events with the subjects via email or telephone conversation.

After combining the findings across the data sources, the researcher constructed a narrative of any conclusions which emerged. The methodology served as a powerful means of exploring how users took up the ideas of other and how VMCAnalytics were changed in response to interviewer, reviewer, or peer input.

CHAPTER 4 RESULTS

4.1 S1: Alan's Infinity

4.1.1 Overview

S1 began the Ph.D. program in 2012. She had 5 years of teaching experience teaching middle school, 6 years of teacher educator experience teaching math in elementary school, modern high school math, secondary math methods, and secondary math practicum, 6 years of research experience, and 22 years of textbook writing and editing experience. She was introduced to the VMC through two classes that she took at Rutgers as part of the M.Ed. program in January of 2011 and to the VMCAnalytic tool through Dr. Carolyn Maher. S1 created a first draft of her VMCAnalytic as part of a larger analytic that she used as part of her qualifying exam to show student argumentation. She then separated events from that larger analytic and created the VMCAnalytic under study to be used for her dissertation research. As part of her research, S1 used her VMCAnalytic as a teaching tool with preservice teachers to support their learning about argumentation. S1 shared that she created the VMCAnalytic to show evidence of Mathematical Practice 3 of the Common Core State Standards, Construct viable arguments and critique the arguments of others. She stated that she wanted to show students participating in argumentation as described by the standard and extant mathematics education.

S1's VMCAnalytic was entitled "Fourth graders' argumentation about the density of fractions between 0 and 1." Prior to creating this VMCAnalytic, S1 had created several other VMCAnalytics for a variety of purposes; however, none had as of then been published. Her VMCAnalytic demonstrated students' argumentation as they discussed how many fractions exist between zero and one on the number line. The students featured by the VMCAnalytic used various elements of argumentation, including claims, counter claims, warrants, backing, qualifiers, and justifications. The events in the VMCAnalytic were drawn from a single clip on the VMC, entitled "The infinite number line, Clip 3 of 4: How many numbers between 0 and 1?" which is 16 minutes and 50 seconds long. The VMCAnalytic was composed of 18 events and runs for 13 minutes. The length of the events ranged from 17 seconds to 1 minute and 37 seconds, with an average length of 43 seconds.

In her overall description of the VMCAnalytic, S1 first cited literature to establish the theory that even young children can build proof-like arguments and stated that the purpose of the VMCAnalytic is to show forms of argumentation which arose during student discourse. She then noted that the argumentation depicted by this VMCAnalytic is supported by specific practices of the Common Core Standards for Mathematical Practice. Next, she situated the VMCAnalytic in the context of the larger study by providing the reader with background information about the study, session, and specific clip from which the video events were selected. She also guided the reader how to view additional footage from the clip or from other clips of the session. She then listed the elements of argumentation that will be presented by the events of the VMCAnalytic and summarizes the contents of the events. She concluded by reiterating her motivation for selecting the events and providing guidance about how to watch additional related video footage.

An initial version of the analytic contained 18 events. In these events: 1. Eric challenged the researcher's assertion that there are an infinite number of fractions between the 0 and 1 on the number line; 2. Alan claimed that the segment could be divided into “the smallest of fractions” or even “zillionths”; 3. Erik challenged Alan’s claim, Alan defended his claim, Michael qualified the claim that it would only be possible if the number line was “the longest… in the world”; 4. Alan backed his claim by using the metaphor of a dust particle to help students envision how the segment could be divided into zillionths; 5. Andrew justified Alan’s claim by warranting that by using a microscope you could see that there’s room to divide the segment into tiny fractions, Alan agreed with Andrew, and Michael modified his previous claim and suggested that he might agree with Alan; 6. Brian agreed with Alan and Alan refined his claim and argued that the segment could be divided into pieces smaller than zillionths; 7. Erik used a counterclaim to argue that a microscope does not create more room on the line; 8. Andrew and Alan clarified that the microscope allows you to see the space between a zillionth and zero and Erik questioned them about whether they are claiming that the microscope creates more room or only allows you to see what is already there; 9. Alan refined his argument by saying that the microscope allows you to see space that is there; 10. David used a warrant to explain that a microscope allows you to see “closer”; 11. Audra, Jessica, Beth, and Mark supported Alan’s and Andrew’s arguments; 12. David and Michael supported the argument; 13. Alan drew a magnified view of the segment to back his claim; 14. The researcher restated the argument; 15. Alan justified his argument using his drawing; 16. Brian and Alan further supported the claim; 17. James supported the argument; 18. Brian, David, and Meredith supported Alan’s claim.

As S1 worked with reviewers to revise her VMCAnalytic in preparation for publication, she exchanged 119 emails with them, of which 27 had attached Word documents. Her overall description was updated 14 times in the RUanalytic tool. The first 6 updates were made over the course of two days, 12/22/14 and 12/23/14, before she emailed the reviewers for the first time.

4.1.2 First Cycle of Review

The first cycle of review took place from 12/23/14 until 1/19/15, starting when S1 emailed R1 her first version of the VMCAnalytic and culminating in her email response with an updated Word document reflecting changes based on reviewer feedback.

On 12/23/14, S1 emailed R1 a link to her VMCAnalytic with an attached Word document containing the transcripts of the events and the text of the VMCAnaltyic. The overall description of this version was almost entirely different than the final published version. As in the final version, the description in this version cited research which demonstrated that even young children can engage in proof-like argumentation, stated that the purpose of the VMCAnalytic was to “illustrate events of students involved in argumentation,” and noted that the view of argumentation adopted by this VMCAnalytic was consistent with that of the CCSS. However, this version only provided minimal context and very little description of what occured over the course of the events:

> In this analytic, students in fourth grade are exploring fractions. The problem students have been working on involves placing unit fractions (1/2, 1/3, ¼, and so on, through 1/10) on a number line labeled from 0 to 1. The analytic develops a narrative of students’ argumentation about whether or not an infinite number of fractions can be placed between 0 and 1 on the number line. Some students agree;

some do not. Claims, counter claims, and justifications are all evident in the student discourse.

Additionally, in contrast to the final version, this version described the process of argumentation in great detail as well as details about Toulmin's (1958) model which described the structure of argumentation and definitions of the various elements of argumentation, including claims, data, warrants, backings, qualifiers, and rebuttals.

The first version contained 8 events, in contrast to the final version which contained 18 events. These events were: 1. Alan claimed that the segment of the number line between 0 and 1 could be divided into zillionths; 2. Michael qualified the claim by saying that the number line would have to be "the longest…in the world"; 3. Alan justified his claim using the illustration of a dust particle and Michael and Eric acknowledged the idea by using the examples of small pins or dust bugs; 4. Andrew justified Alan's claim by using the idea of a microscope; 5. Eric used a counter claim to challenge Alan, saying that using a microscope does not create more space; 6. David refuted Eric by further explaining the idea of a microscope; 7. Alan used an illustration to back his claim; 8.The researcher restated the claim, justification, and evidence of Alan's argument.

R1 posted comments in the RUanalytic tool on 12/30/14 in the comments area for the overall VMCAnalytic. She stated that she liked her "use of definitions of the terms." However, interestingly, these definitions were not included in the final version of the VMCAnalytic. Additionally, she recommended the use of a more mathematically precise phrase "segment of the number line between 0 and 1" instead of the phrase "number line labeled from 0 to 1" which was used in the overall description. S1 indicated that she took up this recommendation in her response in the tool on 1/1/15 which states "OK, I made that change." However, the subsequent version which she emailed on 1/19/15 does not reflect this recommendation and still contained the phrase "number line labeled from 0 to 1" in the overall description. This suggestion was repeated in the third cycle of review and the change was implemented at that point.

R1 also posted comments in the RUanalytic tool for individual events on 12/31/14 and S1 responded to her comments on 1/1/15. In the first event, S1 summarized Alan's claim using the term "real number." R1 noted that Alan's claim is about fractions, as opposed to real numbers. S1 took up this comment, made the change, and commented, "OK. I changed 'real number' to 'fraction'."

R1 suggested that, in the fourth event, S1 use Andrew's words to capture the specificity of his language as he discusses the placement of "specific fractions and the tools that can make these visible." S1 questioned this suggestion, saying that she did not understand what R1 meant since she included an exact quote in her description and asked if R1 thought that more of Andrew's argument should be included in the event.

R1 also recommended that S1 remove language from her fifth event that was not part of Eric's argument. S1 responded that she changed it so that it is clearer that Alan presented that portion of the argument prior to the event and that in this event, Erik challenged that claim.

R1 suggested a shorter alternate title for event six, "David reiterates backing for Eric's claim" instead of the longer title S1 had used, "David justifies Alan's claim: David refutes Eric's claim by providing further explanation of the idea of the microscope." S1 initially noted that she accepted this suggestion, commenting, "Ok. I made this change." However, she then questioned the title, saying, "do you mean Alan's claim?," and then suggested an alternative title: "David reiterates backing for Alan's claim by providing further explanation of the idea of the microscope."

Similarly, R1 suggested that S1 use the term "drawing" in her title for event seven instead of the phrase "visual representation." S1 noted her acceptance of this proposal and, as will be discussed below, updated the title accordingly.

Event eight encapsulated two ideas, the restatement of Alan's argument by the researcher and Alan's refinement of his argument. R1 recommended that S1 split the event and create two events from it. S1 indicated that she agreed with this suggestion by saying "OK" and subsequently split the event into two separate events, as will be discussed.

On 1/12/15, R2 posted comments via the tool related to the overall VMCAnalytic. She agreed with R1's recommendation regarding the phrasing "segment of a number line," additionally suggesting phrasing such as "with labels for the points 0 and 1." R2 also asked questions and made additional recommendations. Most of the comments were related to clarifying or providing examples of the terms for the elements of argumentation that were introduced in the overall description. These comments included the following:

1. R2 recommended that S1 identify the terms that she introduced in her overall descriptions "somewhere in the descriptions" to improve clarity. This recommendation addressed the fact that although some of the event titles noted elements of argumentation that were shown in the event, the event descriptions mainly summarized

the events that occurred but did not explain how students in those events employed specific elements of argumentation.

2. R2 questioned whether or not the VMCAnalytic defined the term “counterclaim.” Although the description noted that counterclaims are evident in student discourse and event 5 showcased an example of a counterclaim, the term was not defined in the overall description.

3. R2 also questioned whether or not the VMCAnalytic contained an example of a “rebuttal.” This question addressed the fact that although the term rebuttal was listed in the description as a possible element of an argument and was defined, no event addressed a rebuttal.

4. R2 asked what S1 would consider “data.”

5. R2 asked a related comment, questioning S1’s definition of “data” as “evidences that support the claim.” R2 questioned the definition saying, “Isn’t ‘data’ more general than just ‘supporting the claim.’” She further asked whether or not it would include “all of the material that you study,” which might support a claim, provide a counter example, or might be irrelevant.

R2 also asked S1 about whether or not any of the students actually stated that 1/100 or some other small fraction could not be placed on the number line. It is unclear why she asked this question. Additionally, R2 recommended that S1 be consistent in her use of language. It is not clear in reference to what language this comment was made.

R2 also commented on individual events via the RUanalytic tool. In a comment on the first event, R2 noted that she did think that a quotation of Alan’s claim was accurate and that he said “you could divide from zero to one *into* the smallest of fractions" rather than "it's the smallest of fractions." She also suggested that since the second event was so short (just 9 seconds long), perhaps the first and second events could be combined.

In reference to the third event, R2 shared her experience reviewing another VMCAnalytic related to representations that "underscored… the importance of experience or context" and therefore suggested that S1 "point… out somewhere" that Alan's argument regarding the dust particle came from his experience and to perhaps note that it is a warrant for his claim. Similarly, R2 noted that Andrew's use of the idea of a microscope in the fourth event was also a "warrant from experience - or context." She suggested that S1 use terminology related to argumentation, such as qualifier or "whichever… is the correct one" to explain how Andrew's argument related to Alan's claim.

R2 questioned S1's categorization of Erik's argument in the fifth event as a counterclaim. She said, "I don't think Erik is rebutting Alan's claim or even making a counter claim - just raising another of his contextual experiences… about the nature of mathematical reality… what does it mean to say there is 'space between 0 and 1' - let alone 'more space'?" She also noted that S1 had not defined the term counter claim in her overall description and asked her to use a term that was defined in the overall description to explain what element of argumentation Erik was using. She agreed that David's argument in the sixth event justified Alan's claim, but added that it "seems to me [that he justifies] Erik's claim as well" and asked if the event could run a bit longer. S1 responded that the video fades out after the footage included in the event.

S1 addressed the comments in an updated Word document version which she emailed on 1/19/15. As noted in her email, she did not update the VMCAnalytic in the tool at this point. She notes in her email that “There were some places where I couldn’t resolve your [R2’s] queries.”

In this second version, S1 edited her overall description, rewording and rearranging sentences. In a comment in the document, she noted that the “first part” of the overall description was copied from another VMCAnalytic that she was working on related to argumentation. In this description, she removed the diagram of Toulmin’s model but added a paragraph to describe the differences between a claim and a conjecture.

Additionally, S1 took up many of R2’s comments. She addressed her concern relating to the definition of the term data by broadening her definition of the term to include evidences used to support counterclaims. As recommended by R2, she also added a definition for the term counterclaim, which had previously been left undefined. She also removed her definition of the term rebuttal and did not list it as evident in student discourse in one sentence; however, she left it in a list of elements of argumentation in another paragraph.

Importantly, S1 took up R2’s first suggestion to identify the terms in the descriptions. Thus, in the second event, S1 added a sentence to explain why Michael’s statement was a qualifier. In event three, S1 noted that Alan provided evidence for his claim. In the fourth event, S1 stated that Andrew’s idea of a microscope was a warrant and explained why. In the fifth event, S1 described how Eric’s counterclaim countered Alan’s claim. She noted, though, in a comment in the document, that R2 ”does not think that this is a counterclaim.” In the next event, S1 added that David’s support for Alan’s claim was a reiteration of a backing for the claim. These changes, which, as noted, were introduced in response to a comment from R2, greatly improved the coherence of the VMCAnalytic since it connected the events to the overall theme and explained how they showed evidence of the various elements of argumentation.

S1 took up many of the comments which R1 and R2 made relating to the individual events. Taking up R1's suggestion to use the term "fraction" instead of "real number," S1 updated the description of the first event to use the term "fraction" instead of "real number." However, although R2 noted that she did think that a quotation of Alan's claim, "it's the smallest of fractions" was accurate and that he said "you could divide from zero to one into the smallest of fractions," S1 did not update either the transcript or description text in this version. In a later version sent on 2/3/15, S1 did indeed update the transcript that she included in the Word document; however, she did not actually update the quote that she used in her description. In a document she sent on 3/23/15, S1 did update the quote used in the description.

S1 acknowledged R2's recommendation to combine the second event with the first since the second event was very short in a note in her Word document. However, she did not actually combine the events in her new version. Additionally, S1 only partially took up R2's insight that the idea of a dust particle introduced in the third event came from Alan's experience and could perhaps be considered a warrant. She did add that Alan provided "evidence using an idea from his personal experience, the size of a dust particle." However, she did not use the term warrant or any other term from Toulmin's model to identify the element of argumentation that Alan used. Interestingly, in the fourth event, S1 did take up R2's comment that the idea of a microscope was perhaps a warrant or a qualifier, and updated the title of the event to be “Andrew’s warrant: Andrew uses the idea of a microscope as a warrant,” using the term warrant instead of justification to describe Andrew’s argument. As in event three, S1 took up R2’s comment that the idea of a microscope also came from experience, and therefore added that that the idea was “from Andrew’s own experience of a microscope.” However, she did not take up R1’s suggestion to use Andrew’s words with which “he talks about the placement of specific fractions and the tools that can make these visible.” She acknowledged the comment but indicated that she did not know what R1 meant by the comment and asked, “should I include something more/else in the event? I have quoted Andrew exactly in the description, so I’m not sure what other words of his I should use.”

S1 took up R1’s comment on event five in which R1 suggested that S1 eliminate the phrase in the description, “that there is enough space on the number line between 0 and 1 to put fractions through zillionths,” changing the description to clarify more explicitly that Alan had claimed that there is enough space and that Eric challenged the claim. R2 then took up these comments, noting that she does not “think Erik is rebutting Alan’s claim or even making a counterclaim” but is rather just “raising another of his contextual experiences” and questioning what Alan means when he says that there is “more space” between 0 and 1. S1 took up R2’s comment and added a sentence to explain how she viewed Erik’s argument as a counterclaim: “This counterclaim is meant to contradict the claim that there is enough space between 0 and 1 to put fractions through zillionths.” She also took up R2’s comment which noted that counterclaim was not defined as a term of argumentation in the overall description, saying that she added a definition for the term counterclaim in the overall description.

S1 took up R1's suggestion to modify the title for event six. S1 had entitled the event, "David justifies Alan's claim: David refutes Eric's claim by providing further explanation of the idea of a microscope." R1 suggested modifying the title to "David reiterates backing for Eric's claim." S1 took up the comment and responded that she made the change, but then asked, "do you mean Alan's claim?" She then suggested modifying the title to "David reiterates backing for Alan's claim by providing further explanation of the idea of the microscope." However, in the version that she sent on 1/19/15, the event was entitled, "David refutes Eric's claim and supports Alan's claim." Thus she partially took up R1's suggestion to modify the title, shortening it, but not incorporating all the ideas R1 suggested should be included in the title. R2 agreed with S1 that David justified Alan's claim, and noted that it seemed that he justified Erik's claim as well. S1 did not address this comment and it is unclear what R2 meant. R2 also suggested lengthening the event; however, S1 explained that the video "fades out right after this."

S1 modified the title of her seventh event to use the term "drawing" instead of "visual representation." Thus, she took up R1's suggestion to use the term drawing in her title rather than visual representation.

Additionally, S1 split what had previously been her last event, event 8, into two separate events, taking up R1's suggestion to split the events. In the first, she included the researcher's restatement of Alan's claim, and in the second, she included Alan's refinement of his argument using the drawing of the number line. Although she did not combine them, S1 noted in a comment that R2 thought that events one and two could be combined into one event.

4.1.3 Second Cycle of Review

On 1/20/15, R1 emailed S1, noting that her new version “looks fine,” and made two additional comments. First, she recommended the use of the phrase “infinitely many” instead of “infinite number,” and, second, she directed S1 to “use students’ exact language, in quotes.” In a subsequent email that same day, in response to a question from S1 about whether or not the VMCAnalytic was ready for publication, R1 wrote that she and R2 would conduct a final review of her VMCAnalytic since it was close to publishable form. She also recommended that S1 request input from another reviewer with expertise in researching students’ use of proof.

On 1/21/2015, S1 emailed R1 and R2, alerting them that she had found “what would be called the raw video for Alan’s Infinity” on the VMC. She noted that this clip contains footage of many more students’ arguments, and stated that she planned to redo the VMCAnalytic to use the newly discovered clip. Thus, S1 redid her VMCAnalytic, incorporating events and descriptions from her original VMCAnalytic and implementing changes which addressed the comments made by R1 regarding her old VMCAnalytic.

On 2/3/2015, S1 emailed R1 and R2 with an attached Word document containing the text of her new VMCAnalytic based on the newly discovered clip. She noted that she added the new events and their titles to the end of her old VMCAnalytic in the RUanalytic tool, but did not add descriptions of the events in the tool yet, although they were included in the document.

In this new version, the overall description was modified but, according to a comment in the document, did not include the “complete text.” Thus, it was significantly shorter than the description in the previous version. Although its three paragraphs were almost identical to three of the paragraphs of the previous version, they did contain some changes. The paragraphs described the previous research on argumentation, noted that the view of argumentation adopted by this VMCAnalytic is consistent with that of the CCSS, and provided a brief overview of the context and content of the VMCAnalytic. In addition to some minor wording changes, two more significant changes were made to these paragraphs. First, the purpose of the VMCAnalytic was described as an illustration of “social argumentation during which students are interacting with each other and a researcher” rather than just an illustration of “argumentation.” Additionally, the wording “infinite number” was modified to “infinitely many numbers,” taking up R1’s suggestion to use the phrase “infinitely many” rather than “infinite number.”

In this version, too, the VMCAnalytic was expanded to include 17 events using footage not available in the video drawn from previously. These events included the following, with the new events noted in italics: 1. *The researcher claimed that there are infinitely many numbers between zero and one and Erik questioned the claim;* 2. Alan claimed that the distance from 0 to 1 could be divided into “zillionths”; 3. *Erik challenged Alan’s claim with a counterclaim*, Michael limited the strength of the claim using a qualifier to explain that it would only be possible if the number line was “the longest… in the world”; 4. Alan provided evidence for his claim with an idea from his personal experience, a dust particle and Michael indicated that he understands the idea; 5. Andrew justified Alan’s claim by warranting that by using a microscope you could see that there’s room to divide the segment into tiny fractions, *Alan agreed with Andrew, and Michael modified his previous claim and suggested that he might agree with Alan;* 6. *Brian agreed with Alan and Alan refined his claim and argued that the segment could be* *divided into pieces smaller than zillionths;* 7. Erik used a counterclaim to argue that a microscope does not create more room on the line; 8. *Andrew and Alan clarified that the microscope allows you to see the space between a zillionth and zero and Erik questioned them about whether they are claiming that the microscope creates more room or only allows you to see what is already there;* 9. *Alan refined his argument by saying that the microscope allows you to see space that is there and the researcher clarified the arguments that were being made;* 10. David used a warrant to explain that a microscope allows you to see "closer;" 11. *Audra, Jessica, Beth, and Mark supported Alan's and Andrew's arguments;* 12. *David refined the argument and Michael showed that his thinking has evolved to support the argument;* 13. Alan drew a magnified view of the segment to back his claim; 14. The researcher restated the argument; 15. Alan refined his argument using his drawing; 16. *Brian and Alan further supported the claim;* 17. *James, Brian, David, and Meredith supported Alan's claim*.

The changes to events that had been included previously were implemented so that they would flow with the new events. In 16 of the 17 events, S1 used quotes from the transcript in the descriptions, taking up R1's suggestion to "use students' exact language, in quotes."

4.1.4 Third Cycle of Review

On 2/4/15 and 2/26/15 R2 emailed edited versions of the document S1 sent, noting that she thinks "this is really good" (2/26/15), but that she "added a couple of edits" (2/4/15) and "made a few notes" (2/26/15). Aside from a few minor wording edits, R2 made two suggestions on 2/4/15:

1. Reword the sentence, "The events show forms of arguments that naturally occur in a student's mathematical argument" so that the term argument is not used twice (2/4/15).
2. Situate the VMCAnalytic in the broader longitudinal study and note that at the time that the events of the VMCAnalytic took place, the students had not yet been formally introduced to operations with fractions (2/4/15).

Additionally, on 2/26/15 R2 commented on S1's interpretation of video. Regarding the video event in which Erik said "If your one whole is ten you can't divide it into zillionths," R2 noted, "My thought is that he is thinking of a 'one whole' divided into 10ths-??? So of course you can't divide it into anything else!"

She then questioned S1's interpretation of Erik's claim that "if you're using a microscope to give more space in actuality you're not getting more space." S1 interpreted this statement to be a counterclaim that contradicted "the claim that there is enough space between 0 and 1 to put fractions through zillionths." R2 commented that she is "not convinced" that that was what Erik meant to say.

Additionally, R2 made a few comments in the RUanalytic tool. She questioned whether perhaps Erik thought that "infinitely many numbers" referred to "infinitely many whole numbers" and that perhaps that is what didn't "make sense to him." Additionally, she asked what Erik said at the end of event 8 since it ended mid-sentence. In her comment posted on 3/14/2015, S1 explained that Erik's statement in event 8 that "it's not true" was not cut short by the tool, but rather was cut short when Alan spoke afterwards. She also explained that she thought Erik meant that "it is not true that the microscope gives you more space on the number line."

R1 emailed an edited version of the Word document with her comments on 2/25/15. In addition to some wording changes, she questioned S1's emphasis on "social argumentation" and questioned whether or not she distinguished between "social argumentation" and "argumentation," and deleted the word "social" from the description. Additionally, she edited the paragraph used to situate the events, modifying the phrase "number line labeled from 0 to 1" to be "segment of a number line labeled from 0 to 1." She also commented that S1 should use the phrase "infinitely many fractions" instead of "infinitely many numbers of fractions" since the phrase "infinitely many numbers" is a contradiction. On 2/26/15, R2 added a related comment, recommending the use of the phrase "an infinite number of fractions."

R1 also commented on the event descriptions. She asked S1 to clarify what Erik's counterclaim was, and noted that Alan's subsequent assertion was perhaps a re-assertion. She also asked for clarification of a statement in which Erik asserted that Alan had discussed extending the number line. Additionally, she recommended that S1 explicitly note the referents that students refer to in the video.

After receiving feedback on her event descriptions, S1 created a document with the text of the overall description for her VMCAnalytic and emailed it to R1 and R2 on 2/28/15.

In this version of the overall description, S1 removed the first and second paragraphs that had referenced research that showed that young children can build proof-like forms of argument and noted the Common Core Standards practices that support the view of argumentation presented by the VMCAnalytic. Her third paragraph was incorporated into a larger narrative which explained the context of the events in the

VMCAnalytic. In her text, S1 took up R1's and R2's suggestion to use the phrase "infinitely many fractions" as well as R1's suggested edit to use the phrase "segment of a number line labeled from 0 to 1."

The overall description situated the VMCAnalytic in the context of the longitudinal study and the specific session and clip from which the events were drawn. It described the content of the sessions which led up to the session from which the events in the VMCAnalytic were taken and noted that the students had not yet been formally introduced to operations with fractions. Thus, she took up R2's suggestion to "situate this in the longitudinal study - and comment that the students have not formally been introduced to operations with fractions."

In addition, the description guided the reader how to view additional footage from the clip or from other clips of the session, listed the elements of argumentation that are shown in the events of the VMCAnalytic, and summarized the contents of the events. She concluded by reiterating her motivation for selecting the events and providing guidance about how to watch additional related video footage.

On 3/2/15 R1 emailed S1 edits and comments for the overall description of her VMCAnalytic. In addition to wording edits, she commented that the first sentence of the overall description was too broad and recommended that S1 be more specific about the fourth grade students and fraction ideas that were examined by the VMCAnalytic. She also recommended that S1 reference the related NSF grant that provided funding for the original study. S1 responded by asking which grants applied to the data set covered by the VMCAnalytic and noted that another of her VMCAnaltyics did not reference the NSF grants.

S1 responded to R1’s feedback on 3/2/15, emailing a new version of the overall description which incorporated changes “based on [their] conversation.” She accepted the wording changes that R1 suggested. She also reinserted the first and second paragraphs that referenced research that showed that young children can build proof-like forms of argument and noted the Common Core Standards practices that support the view of argumentation presented by the VMCAnalytic. She then took up R1’s suggestion to be more specific about the what fraction ideas are described by the VMCAnalytic, stating that, “fourth grade students are arguing about whether or not infinitely many fractions can be placed between 0 and 1 on the number line.” She also took up R1’s suggestion to reference the related NSF grant, noting the grant that supported the research.

In addition, S1 updated the VMCAnalytic in the RUanalytic tool on 3/2/15. In event three, she took up R1’s suggestion to clarify Erik’s counterclaim. She also took up R1’s question as to whether or not Alan’s assertion was a re-assertion, replacing her language of “Alan asserts” with “Alan defends his claim by emphasizing.” She further took up R1’s suggestion to modify her wording in event five to be more specific about the event to which she was referring.

S1 also took up R2’s comment on event seven in which she said that she is “not convinced” that Erik’s counterclaim contradicted “the claim that there is enough space between 0 and 1 to put fractions through zillionths.” Instead of stating that the counterclaim “contradicts the claim,” S1 now stated, “This counterclaim suggests that Erik believes that by claiming that there is enough space on the number line between 0 and 1 to plot fractions through zillionths... Alan and others are claiming that when you use a microscope you ‘get more space.’ Erik’s counterclaim contradicts this claim.”

In event nine, S1 took up R1's comment, which noted that the language of the description was unclear. She clarified that Erik confirmed "that Researcher Maher has represented his position accurately and asserts that he believed that in the first claim that Alan made, Alan was talking about extending the number line." She also took up R1's suggestions for events thirteen and fifteen to describe referents from the video, greatly enhancing the description of both events to explain the diagram to which Alan referred in his argument.

During this cycle of review, S1 and her reviewers discussed possible titles for her VMCAnalytic. This conversation was initiated by S1 on 2/25/15 when she asked in an email, "Something to think about -- for Alan and Stephanie analytics, what do we want to name them?" On 2/26/15, R2 recommended the title "capture not just the concept of infinity - but also density." In her email to R1 on 3/2/15, S1 asked R1 to discuss possible titles for her VMCAnalytic.

S1 also asked for guidance on locating papers that may have been published related to the video that her VMCAnalytic drew upon so that she could "reference it in the overall description of [her] analytic." In response, R1 emailed her a reference to a videotape and CD produced in 1994 which included the video, noting that perhaps a paper was written "about that time." R3 responded that he was unaware of any paper related to the specific video used in the VMCAnalytic although there were two papers published about related video. He recommended checking the references of a dissertation that analyzed the video. R5, too, responded that she was not aware of any papers that discussed the video. In her email to S1 on 3/2/15, R1 recommended that S1 reference additional dissertations and publications. In response, S1 requested that R1 talk with her about what papers she might reference since the clip on the VMC only referenced Suzanna E. Schmeelk's unpublished doctoral dissertation. R1 then confirmed that she discussed it with R4 and that Suzanna E. Schmeelk's unpublished doctoral dissertation was the only related publication.

4.1.5 Fourth Cycle of Review

On 3/3/15, R2 emailed S1 with two comments for the overall description. She reiterated that she hoped that the title for the RUanalytic would capture "the idea of density of rational numbers between zero and 1 rather than referring simply to the mathematical concept of infinity." She also asked what S1 meant when she stated that "Michael qualifies when he believes Alan's claim can be true," asking, "His original claim?? Or which additional one?? What do you mean by 'when'?"

R1 and R2 also added comments via the commenting tool on 3/13/15 and 3/14/15, and S1 responded to these comments on 3/14/15 and 3/15/15. In the comment section for the overall description, R1 suggested that they "think together about" the title for event 17 since it "is not helpful," perhaps due to the "richness of the event." S1 responded that she would "like to talk more" about the event.

In reference to event five, R1 suggested that S1 use the language of a "tool" to refer to the microscope instead of using the word "idea." S1 took up this idea and modified the text of her overall description, but did not update the text of event five. R2, however, in reference to the overall description, said that she "wouldn't say introduce the microscope as a tool - since it was not actually there," so S1 modified her description to address both concerns, using the wording "introducing the idea of a microscope as a tool."

R2 made two additional recommendations for the overall description. First, she suggested that S1 clarify which claim is referred to by the statement, “Alan supports this claim by making a claim of his own.” S1 responded that she modified the description by changing “this claim” to “the original claim made by mathematicians.” Second, she noted that the description referred users to the clips in two separate paragraphs and cautioned that S1 should ensure that the paragraphs are not repetitious. S1 responded by noting that she modified the last paragraph, including the new text in her comment.

R2 asked S1 to clarify a sentence in event seven in which she explained Erik’s counterclaim that using a microscope does not create more space. S1 responded by posting a more clearly stated explanation of Erik’s counterclaim. R2 also recommended that S1 state that “Erik thought that Alan was ‘extending’“ the number line, rather than state that “Erik was thinking about ‘extending’ the number line.” S1 responded that this distinction was clarified in the last paragraph, but that she nonetheless modified the description to explain that “Erik thought that Alan meant ‘extending’ the number line.”

Additionally, R1 suggested that S1 entitle event sixteen more precisely to explain what the “refined” claim is. S1 responded that she changed the title to “Brian and Alan further support refined claim that the number line can be divided up into smaller and smaller sections.” R1 also proposed that perhaps event seventeen “should be broken up” and that the title should be modified to reflect the “richness of the discussion.” S1 agreed and commented that they “need to talk more about this” since she is “not sure how to address this.”

On 3/15/15, S1 emailed R1 and R2 to inform them that she updated the RUanalytic based on their comments and suggestions, noting that event 17 was not updated since she was "not sure what changes to make."

In this version, in addition to implementing some minor recommended wording changes, S1 took up the other suggestions recommended by her reviewers. S1 took up R2's suggestion to include the idea of fraction density in the RUanalytic title and entitled the RUanalytic "Fourth graders' argumentation about the density of fractions between 0 and 1." Taking up additional recommendations from R2, S1 also clarified that the claim that Alan supported was the "original claim made by mathematicians" and explained that Andrew introduced the "idea of using a microscope as a tool." S1 also took up R2's advice to ensure that her reference to the VMC clips was not repetitious, noting briefly in her last paragraph that the clips were "mentioned previously."

S1 took up R1's suggestion to use the word "tool" to describe the idea of a microscope when summarizing event five in the overall description. Additionally, she extended her uptake to also use the word "tool" to refer to the idea of a dust particle in event four. In event nine, S1 took up R2's recommendation to clarify that Erik "thought that Alan meant 'extending' the number line" rather than merely stating that "Erik was thinking about 'extending' the number line." Also, as mentioned above, S1 took up R1's suggestion to refine her title for event sixteen, implementing the change she proposed in her response.

Finally, following an invitation in this cycle of review from R1 to discuss the event with her and R2, S1 sent a document on 3/16/15 containing a short summary of each event, the text of a revised event 17, as well as a new event, event 18, created from the division of the previous version of event 17 into two separate events. In event 17, S1 added that "Researcher Maher invites children who have not participated in the argumentation, thus far, to state their ideas." She also clarified that James agreed with the claim of Alan and Andrew that "you can place more and more numbers on the number line." Event 18 highlighted the contributions of Brian, David, Gregory, and Meredith.

4.1.6 Fifth Cycle of Review

On 3/18/15, R2 sent two documents to S1, one with edits of S1's suggested event titles with her and R1's changes tracked, and one with her and R1's final title suggestions. S1 then incorporated the changes into a new Word document which she emailed to R1 and R2 on 3/23/15. In this version, she accepted all the suggested titles and updated the titles accordingly. Additionally, she updated her descriptions to incorporate suggestions made by the reviewers.

The following are S1's original suggested event titles, the reviewers' final suggested edits to those titles, the reviewer's suggestions for modifications to the event descriptions (some of which incorporate parts of S1's original event titles), and the uptake of those suggestions as reflected by the changes S1 made to her event descriptions.

1. *Original title*: The researcher makes an initial claim: There are infinitely many fractions between zero and one and Erik challenges that claim
   Suggested title: Eric's challenge to researcher's initial claim about density
   Suggestion: Start description with a quote of the researcher's claim.
   Change: Noted that Researcher Maher made an "initial claim about density" and included a quote of her claim.

2. *Original title:* Alan claims that you can divide the distance between 0 and 1 into zillionths.

   Suggested title: Alan's counter claim

   Suggestion: Begin with: Alan supports researcher, claims that you can divide the distance between 0 and 1 into zillionths.

   Change: Noted that Alan supported the researcher's claim and made a related claim that the "distance between 0 and 1 on the number line can be divided into zillionths."

3. *Original title:* Erik challenges Alan's claim, makes a counterclaim, and Michael presents a qualifier

   Suggested title: Discourse among Erik, Alan, and Michael

   Suggestion: Start the event description with what was in the original title

   Change: Noted that in this event, Erik challenges Alan's claim, "Alan defends his claim, and Michael presents a qualifier" and then described how Erik challenged Alan's claim, how Alan defended his claim, and how Michael presented a qualifier.

4. *Original title:* Alan presents evidence using the illustration of a dust particle

   Suggested title: Alan's dust particle metaphor

5. *Original title:* Andrew presents a warrant to Alan's claim and Michael modifies his claim *Suggested title:* Discourse among Andrew, Alan and Michael

   Suggestion: Start description with R2's proposed title: Andrew's warrant to Alan's claim and Michael modifies his claim

Change: Noted that "Andrew presents a warrant to support Alan's claim and Michael modifies his claim."

6. *Original title:* Alan refines his claim and Brian modifies his claim

   Suggested title: Alan and Brian refine and modify the claims

   Suggestion: Begin with "Alan refines his claim and Brian modifies his claim," clarify what Brian's claim was and where it was made

   Change: Noted that in the event, "Alan refines his claim and Brian modifies his claim." Also added that Brian is modifying "an earlier claim that infinitely many fractions cannot be placed on the number line."

7. *Original title:* Erik presents a counterclaim: when using a microscope, you are not getting more space

   Suggested title: Erik's counterclaim using microscope as tool

   Suggestion: Start with Erik's counterclaim "when using a microscope, you are not getting more space."

   Change: Noted that "In this event, Erik presents a counterclaim: With a microscope, there is not more space."

8. *Original title:* Andrew, Alan, and Erik clarify their arguments and claims about the microscope and "more space"

   Suggested title: Clarification of claims by Andrew, Alan, and Erik

   Change: Started off the description with the original title.

9. *Original title:* Alan refines his argument and Researcher Maher clarifies Alan's and Erik's arguments

Suggested title: Clarifying the arguments of Alan and Erik

Change: Started off the description with the original title.

10. *Original title:* David presents a warrant to support his claim: you are not seeing more, you are just seeing closer

    Suggested title: David's warrant for the claim

    Suggestion: Begin with David's warrant that: you are not seeing more, you are just seeing closer

    Change: Began description with original title as suggested

11. *Original title:* Audra, Jessica, Beth, and Mark state and support their positions about the claims being made

    Suggested title: Support for David's claim from Audra, Jessica, Beth, and Mark

12. *Original title:* David further clarifies the claim about space

    Suggested title: David further clarifies his claim

13. *Original title:* Alan uses a drawing to present backing for his claim that you can use a microscope to see more and more space on the number line

    Suggested title: Evidence: Alan's drawing of a magnified segment

14. *Original title:* Researcher Maher restates Alan's argument

    Suggested title (no change): Researcher Maher restates Alan's argument

15. *Original title:* Alan refines his argument, including the claim, the justification, and the evidence

    Suggested title: Alan refines claim, providing justification and evidence

16. *Original title:* Brian and Alan further support the refined claim that the number line can be divided up into smaller and smaller sections

Suggested title: Brian and Alan provide additional support

Suggestion: Start with: Brian and Alan…. for the claim that the number line can be divided up into ever smaller sections

Change: Started with "Brian and Alan further support the refined claim."

17. *Original title:* James agrees with Alan and Alan continues to refine his argument

    Suggested title: Concurrence from James with Alan's argument

18. *Original title:* Brian, David, and Meredith agree that you can plot an infinite number of fractions between and 0 and 1 on the number line and the argument about density is resolved

    Suggested title: Consensus from class; the voice of Brian, David, and Meredith

    Suggestion: Start with: Brian, David, and Meredith agree that an infinite number of fractions exist between 0 and 2 on the number line

    Change: Added that "there is consensus from the class as voiced by Brian, David, and Meredith that an infinite number of fractions exist on the number line between 0 and 1."

On 3/23/15 and 3/24/15 respectively, R1 and R2 separately emailed edits for the document that S1 had sent on 3/23/315. R1 made wording edits to the overall description. She also edited the wording in event seven to describe the use of the microscope as a tool. R2, too, made wording edits to the overall description. In addition, she recommended that S1 situate the session "as session #... in the intervention of however many sessions." She also questioned S1's use of the word "tool" in event four to describe the metaphor of the dust particle, suggesting that perhaps the word image or metaphor, which S1 already used, is more appropriate. Additionally, R2 questioned S1's description of event six which said that "Alan refines his claim and Brian modifies his claim." R2 noted that as she read the transcript, she felt that "Brian is reinforcing - or agreeing with Alan's claim - which Alan then refines." She also noted again that Alan "doesn't really use a microscope" in event seven and edited the text to make that distinction more clear. Thus, she replaced the phrase "With a microscope as a tool, he argues that there is not more space" with "Proposing the use of a microscope as a tool, he argues that there is not more space."

On 4/2/15, S1 emailed the event titles to R2 and R1 for a final review. In this version, the titles of events two, six, and twelve were updated. The title of event two was updated from "Alan's counter claim" to "Alan's claim." The title of event six was changed from "Alan and Brian refine and modify the claims" to "Brian agrees with Alan's claim and Alan and refines his claim." Finally, the title of event twelve was modified from "David further clarifies his claim" to "David and Michael further clarify the claim."

That same day, R1 responded with edits, shortening the titles so they would not "give away" the contents of the events. Later that day, R2 emailed S1, agreeing with the titles and saying that "these look good to me," and S1 responded to R1, saying that she "[g]ot it, thanks!" The next day, on 4/3/15, S1 updated the text of her RUanalytic in the RUanalytic tool. In this version, S1 also accepted most of the latest titles which R1 recommended, including her suggestion to incorporate the longer wording of her old titles into her descriptions.

The list below details the changes to the titles which R1 suggested. It compares the original titles that S1 sent on 4/2/15 with the recommended titles that R1 suggested later that same day. Additionally, it notes the updates to the description which S1 incorporated on 4/3/15 as well as the actual titles used by S1 on 4/3/15 when they were different than R1's suggested titles.

1. *Original title:* Eric's challenge to researcher's initial claim about density

   Suggested title: Eric challenges claim about density

   Description update: "Erik challenges the researcher's initial claim about density" instead of "Erik challenges this claim."

2. *Original title:* Alan's claim

   Suggested title: Alan proposes a claim

3. *Original title:* Discourse among Erik, Alan, and Michael

   Suggested title: Voices of Erik, Alan, and Michael

   Description update: "This event captures the discourse among Erik, Alan, and Michael."

4. *Original title:* Alan's dust particle metaphor

   Suggested title: Alan offers a metaphor to back claim

5. *Original title:* Discourse among Andrew, Alan, and Michael

   Suggested title: Voices of Andrew, Alan, and Michael

6. *Original title:* Brian agrees with Alan's claim and Alan refines his claim

   Suggested title: Voices of Brian and Alan

7. *Original title:* Erik's counterclaim using microscope as tool

   Suggested title: Erik suggests a tool

   Title used by S1: Erik presents a counterclaim

8. *Original title:* Clarification of claims by Andrew, Alan, and Erik

Suggested title: Clarifications by Andrew, Alan, and Erik

9. *Original title:* Clarifying the arguments of Alan and Erik

   Suggested title: Alan and Erik's argument

   Title used by S1: Alan's and Erik's argument

10. *Original title:* David's warrant for the claim

    Suggested title: David's warrant

11. *Original title:* Support for David's claim from Audra, Jessica, Beth, and Mark

    Suggested title: Support by Audra, Jessica, Beth, and Mark

12. *Original title:* David and Michael further clarify the claim

    Suggested title: Clarification by David and Michael

13. *Original title:* Evidence: Alan's drawing of a magnified segment

    Suggested title: Alan's drawing

    Description update: "In this event, Alan uses a drawing of a magnified line segment as evidence for his claim."

14. *Original title:* Researcher Maher restates Alan's argument

    Suggested title: Restatement of Alan's argument

15. *Original title:* Alan refines claim, providing justification and evidence

    Suggested title: Alan offers justification and evidence

16. *Original title:* Brian and Alan provide additional support

    Suggested title: Brian and Alan's support

17. *Original title:* Concurrence from James with Alan's argument

    Suggested title: James supports Alan's argument

18. *Original title:* Consensus from class; the voice of Brian, David, and Meredith

Suggested title: Other voices: Brian, David, and Meredith

As noted in the list above, in the first event, S1 updated the title and did not include the fact that the claim about density was made by the researcher. Instead, S1 added that to the event description instead. Similarly, in the third event, S1 added that the "event captures the discourse among Erik, Alan, and Michael" since the updated title was updated to "Voices of Eric, Alan, and Michael" from "Discourse among Eric, Alan, and Michael." S1 did not take up R1's suggested title for event seven. R1 had suggested the title, "Erik suggests a tool," instead of "Erik's counterclaim, when using a microscope, you are not getting more space." S1 shortened her title, but updated it to, "Erik presents a counterclaim." In the ninth event, S1 again modified R1's proposed title. R1 had suggested, "Alan and Erik's argument," but S1 used "Alan's and Erik's argument" to highlight the fact that they made different arguments. In the thirteenth event, S1 accepted R1's suggested title and incorporated ideas from her old title into her description. Thus, instead of noting in the title, "Evidence: Alan's drawing of a magnified segment," she stated in the description: "In this event, Alan uses a drawing of a magnified line segment as evidence for his claim."

In the RUanalytic update on 4/3/15, S1 also accepted the wording changes which R1 and R2 recommended on 3/23/15 and 3/24/15. Additionally, she took up R2's recommendation to situate the session in the overall description, noting that the "session is the 14th session of 17 sessions of the fraction intervention." Further, in the overall description, she added that Alan's assertion in event 15 was a modification of his claim.

In the fourth event, S1 took up R2's suggestion to describe the dust particle as a metaphor, saying that Alan used a "metaphor of a tool from his personal experience." She also took up R2's interpretation of event six in which R2 had questioned S1's interpretation that Brian modified Alan's claim and argued that Brian reinforced and agreed with Alan's claim. S1 modified her description to explain that Brian agreed with Alan's claim and removed her explanation of how Brian modified his earlier claim. S1 only partially accepted R2's edits for event seven. R2 had updated the description to clarify that Erik didn't actually use a microscope, but rather "proposed the use of a microscope." S1 modified the language to clarify that Erik was not the one who actually propos[ed] the use of a microscope, but rather "consider[ed] the prior suggestion of using a microscope."

Following this last update on 4/3/15, S1's RUanalytic was published.

4.2 S2: Fourth Graders Analyses of Equivalence: 1/5 or 2/10?

4.2.1 Overview

S2, an Assistant Professor of Accounting with additional experience teaching 7th and 9th grade math, started as a part-time student in the Ph.D. for Mathematics Education program in 2012. She created her first VMCAnalytic as part of her coursework in the fall of 2012. She had created several VMCAnalytics, although none had been published, when she created her VMCAnalytic under study, entitled "Fourth Graders Analyses of Equivalence: 1/5 or 2/10?" Her VMCAnalytic explored how revisiting a task helps students build understanding of fraction equivalence. The VMCAnalytic depicted events from two clips from two separate sessions in which students debated and discussed the notion of fraction equivalence. The first four events were culled from a VMC clip entitled "Comparing fractions, a whole class debate, Clip 1 of 5: Is one fifth equal to two tenths?" which was 6 minutes and 18 seconds long, while the last four events were pulled from a

VMC clip entitled “Discovering equivalent fractions and introducing fraction notation, Clip 5 of 5: Compare one half and two thirds, establishing equivalence” which ran for 11 minutes and 6 seconds. S2’s VMCAnalytic took 10 minutes and 12 seconds to view and was composed of 8 events with an average length of 1 minute 16 seconds. The events ranged from a length of 30 seconds to a length of 2 minutes and 45 seconds.

S2’s overall description outlined the theory that underpins her VMCAnalytic and described how the events of the VMCAnalytic illustrate the theory. She began her overall description by citing research that contended that when students revisit mathematical concepts by working on related tasks, they build deeper understanding of those concepts. S2 then explained that the events of her VMCAnalytic followed a prior session in which students expressed uncertainty regarding the nature of fraction equivalence. In the events depicted by the VMCAnalytic which were taken from two subsequent sessions, students revisited the concept of fraction equivalence and could then accurately explain why 1/5 is equivalent to 2/10 and 1/6 is equivalent to 2/12 using the aid of Cuisenaire rods.

The final published version of the VMCAnalytic was composed of eight events. In the first four events: 1. Researcher Carolyn Maher introduced the problem of “Is 1/5 = 2/10”; 2. Meredith built a model to show that the two fractions are equivalent; 3. Brian and Erik further justified Meredith’s argument; 4. The students in the class showed their agreement with the task solution. The last four events were pulled from a separate session in which students worked on the task “Which is larger, one half or two thirds, and by how much.” In these events: 5. Students displayed two different models to solve the task; 6. The researcher highlighted the fact that two different models were used to solve the same task; 7. The students discussed the equivalence of the two solutions and the researcher introduced formal notation to depict equivalence; and 8. The class agreed with the idea that different fractions can be equivalent.

S2's VMCAnalytic was created to support a chapter of a book, Children's Reasoning While Building Fraction Ideas (2017), that describes the development of students' reasoning as they work on a series of tasks that elicit the building of fraction ideas. Importantly, her VMCAnalytic originally began as three separate VMCAnalytics created to support a single chapter. In a reflection paper written shortly after creating her first version of these three VMCAnalytics, S2 wrote that her rationale for creating three separate parts was because they "were culled from different sessions." The VMCAnalytics were then later merged and refined to yield one final VMCAnalytic. The titles of the three original VMCAnalytics were:

1. "Introducing fraction equivalence in a fourth grade classroom: A debate Part I"
2. "Fourth graders comparing fractions, a whole class debate: Is one fifth equal to two tenths Part II"
3. "Fourth Graders discovering equivalent fractions and introducing fraction notation: Comparing one half and two thirds Part III"

Henceforth, the first of the original VMCAnalytics will be referred to as Part I, the second as Part II, and the third as Part III. In her original work, S2 only provided an overall description for Part I. This was later updated to become the overall description of the final VMCAnalytic.

The journey of these VMCAnalytics began on 11/1/13 when R3 emailed S2 with a brief description of the book chapter which would be supported by S2's VMCAnalytics.

As outlined in the book's prospectus, this chapter would focus on students' learning about fraction equivalence and would "document a journey that begins with uncertainty but ends with a clear consensus of a mathematical truth." She specified which three sessions of the study are relevant to this topic, noting that although one session revolved around a fraction comparison task, since the focus of the chapter would be on fraction equivalence, a description of the task should only be "provided in brief." On 11/10/13, R3 followed up with another email, asking S2 to check a much later session of the study which focused on fraction equivalence to see whether or not it could be incorporated into the book section. S2 then created the first version of Parts I, II, and III. The metamorphosis of her three original VMCAnalytics will now be explored, followed by an examination of how the three were combined to form one as well as an analysis of the history of the combined VMCAnalytic.

4.2.2 First Cycle of Review

The first version of the three VMCAnalytics was created on 12/10/13. Importantly, this initial VMCAnaltyic was created in a prior version of the VMCAnalytic tool which did not have a commenting tool and had bugs which presented technical difficulties to users. In this first version, S2's overall description in Part I states that the VMCAnalytic documents students who begin to learn about fraction equivalence and notes that the journey began with uncertainty. She then describes the contents of the events of Part I and outlines what occurred next in Parts II and III.

Part I contained four events. In the first event, the researcher introduced the task that initially gave rise to the discussion of fraction equivalence. The task was to provide a number name for the two white rods when the orange rod is called one. In the next event, Mark and Andrew presented their solution that the two white rods would be called 1/5. In the third event, the researcher asked if anyone had another solution to task, and Meredith, David, Sarah, and Beth offered their solution of 2/10. The researcher then noted that she believed both arguments, the one which claimed that two white rods are called 1/5 and the one which claimed that two white rods are called 2/10. In the last event, the researcher suggested that they leave the controversy for another time. None of these events was included in the final version of the VMCAnalytic but rather encapsulated in the overall description which described the earlier session upon which the later sessions were built.

Like Part I, Part II contained four events. In these events, researcher Carolyn Maher introduced the problem of “Is 1/5 = 2/10,” Meredith built a model to show that the two fractions are equivalent, Brian and Erik further justified Meredith’s argument, and the students in the class showed their agreement with the task solution. These four events later became the first four events of the final VMCAnalytic.

Part III contained five events. In the first event, students stated that 2/3 was larger than ½ by 1/6. Researcher Carolyn Maher asked if anyone had built a second model to solve the task of which is bigger 1/2 or 2/3 and by how much. In the second event, Meredith showed her model for the solution which was different than a model displayed by students earlier. In the third event, the researcher highlighted the fact that others students had found a solution of 1/6 while Meredith found a solution of 2/12. In the next event, students discussed the equivalence of the two solutions, Erik explained how the two solutions are equivalent, and the researcher introduced formal notation to depict equivalence. In the last event, the researcher recapped that two whites could be called 1/6 or 2/12.

In this first version, S2 selected the portions of video that would be included in the events and set titles for them. She did not include descriptions for all of the events in the VMCAnalytic tool, but did write descriptions for all the events in a Word document. In an email dated 12/23/13, S2 explains that she was unable to put the descriptions for the events into the VMCAnalytic tool due to technical difficulties.

On 12/16/13, S2 emailed a Word document with event descriptions to R3 for review, and, in a separate email sent later that day, sent the overall description of Part I for review. The descriptions detailed the content of the video and noted types of reasoning and arguments that were displayed by students. R3 responded that same day, suggesting that S2 add context to Part II and Part III by explaining the tasks that students were working on that prompted the discussion. On 12/18/13, S2 questioned R3 about whether she thought the task context should be added as additional video to the VMCAnalytic or merely summarized as part of the descriptions. R3 did not respond; however, S2 updated the event descriptions of the first events in Parts II and III to provide a more specific context. In Part II, S2 noted that the researcher told the class that they would continue their discussion from a previous session, and in Part III, S2 explained the task that students had been working on and noted that they had created multiple models to represent their solutions. R3 then recommended that S2 request feedback from R1. On 12/23/13, S2 sent an updated version of the Word document to R1 for review. There is no record of a response to this email.

4.2.3 Second Cycle of Review

In July of 2014, S2 merged Parts II and III and created the first version of what would become her final VMCAnalytic. The first evidence of her intention to do so is documented in an email dated 7/29/14. In it she questioned R1 as to whether or not she should combine Parts II and III to create a more comprehensive single VMCAnaltyic. There is no email record of a response. However, in a phone interview, S2 revealed that this email was followed up with a phone conversation in which not only did R1 encourage her to create a single VMCAnalytic, but also suggested that she think about a theory with which to frame her analysis. This conversation proved to be a turning point in the evolution of this VMCAnalytic since it prompted changes which would eventually greatly improve the quality of the three VMCAnalytics. S2's intention to act upon R1's suggestions is evidenced in an email dated later that same day which was sent to VMCAnalytic technical support. In it S2 asked whether or not it is possible to merge VMCAnalytics. Technical support responded on 7/30/14 with instructions on how to create a VMCAnalytic using events from another VMCAnalytic. Later that same day, S2 created the first version of her merged VMCAnalytic.

S2 worked on the new version of her VMCAnalytic, creating multiple versions, until 8/27/14, at which time she submitted her work for review. In this version, S2 completely revamped her overall description, adding a theoretical basis to her work, connecting the events of the VMCAnalytic to its theoretical underpinnings, and describing the newly included events along with their context within the study. She also included the events of only Parts II and III, choosing to describe the events of Part I only in the overall description.

S2 chose to depict the events of her VMCAnalytic as an example of how students are able to enhance and solidify their ideas when they are given a chance to revisit a task which they have previously worked on and discussed with their peers. She began her overall description explaining the theory and referencing research which describes it. She then explained how the events of VMCAnalytic, in which students revisited a task involving fraction comparison, demonstrated this perspective, since students initially were unsure about whether or not different fractions could be equivalent, but upon revisiting the task in later sessions, agreed that this was true. In this version, S2 included events from the two sessions which she previously included in Parts II and III of her earlier version. Thus, in her overall description, she explained the events of the earlier session, and noted that the events of the VMCAnalytic began in a later session. She then described the events of her VMCAnalytic, underscoring how revisiting the task led students to a solidification of their ideas.

In this way, S2 took up important ideas expressed by R1. Although the initial idea of combining the disparate parts of her initial VMCAnalytics was conceived of by S2, she acted upon it only after consultation with R1. Importantly, S2 took up R1's suggestion to portray the events of her VMCAnalytic through the lens of a theoretical framework, greatly enhancing the quality of her VMCAnalytic.

In this version, S2 also modified her event titles and descriptions. To express the fact that this VMCAnalytic built upon the work of a previous session, S2 modified the title of her first event to read, "Reintroducing an Earlier Task" instead of "The task." Additionally, in the description of her first event, she added that the researcher introduced the task “as a reexamination of an activity the class had worked on previously,” thus explicitly relating how the event is related to the theme of the VMCAnalytic.

S2 made similar enhancements to her second event. She improved the event title, making it more specific by calling it ”Meredith Builds a Representation to Equate Two Fractions” instead of her previous and more vague title “Meredith’s solution.” Additionally, she added the words “In this event” to delineate between the context provided before and the description of the actual events of the video included in the event which followed. Importantly, she explicitly related the event to the larger theme of the VMCAnalytic by noting that “although students had not arrived at this conclusion in the previous session, upon revisiting the task, Meredith explicitly equates one fifth and two tenths.” Additionally, she removed a reference to the type of reasoning shown since it no longer related to the theme of the VMCAnalytic.

Similarly, in the third event, S2 removed references to types of reasoning, and in the fourth event, added that “in this session students reach a consensus regarding the solution for a task which had remained unresolved in a previous session,” explicitly relating the event to the overall theme. Moreover, in the fourth event, S2 modified the description to more precisely describe the video in order to express the fact that students reached a consensus. Thus, she wrote that the researcher asked the class whether or not two tenths is equivalent to one fifth instead of incorrectly noting that the researcher stated that fact. The title of this event, too, was updated to more explicitly note that students reached a consensus with “The Class Expresses Their Agreement” instead of the more vague prior title of “Agreeing that 2/10 = 1/5” which did not explain who agreed.

For her fifth event, S2 merged the events one and two of Part III and again explicitly tied the video to her overall analysis. She renamed the event “Revisiting the Concept in a New Task” instead of summarizing the task in the title as she did previously. She then introduced the event description by noting that, “In another session the students revisit the concept of equivalent fractions.” Once again, she used the words “In this event” to make clear when the description of the actual events of the video began following the context provided.

In the sixth event, instead of merely noting that the researcher recapped the arguments, S2 used both the event title and description to focus on the fact that in the video the researcher stressed that the students had presented two distinct solutions for the task. Thus, instead of merely summarizing the video events, S2 used the event title and description to describe the event in the context of her larger narrative.

In the seventh event, too, S2 reworded both the title and description. In her title, S2 underscored the fact that the class discussed the equivalence of the two solutions. She also modified the event description to relate it to her theme, writing that, “In this discussion, which revisits the concept of fraction equivalence in a second problem context, students solidify their understanding of the meaning of equivalent fractions.”

In her eighth and last event, S2 wrapped up the VMCAnalytic by concluding with, “The class concurs with the notion that different fractions can be equivalent.”

In making these changes to her event titles and descriptions, S2 took up R1’s suggestion to base her VMCAnalytic on a theoretical framework. In doing so, and by explicitly tying each event to the larger theme, S2 vastly improved the quality of her VMCAnalytic.

4.2.4 Third Cycle of Review

On 11/20/14, R1 and R2 discussed S2's VMCAnalytic and provided her with feedback in an email. They recommended that she reference dissertations and any other publications that were published about the same video events as her VMCAnalytic. They also recommended that she include the grade level in the title. On 3/29/15, R3 suggested that they revise the title of the book chapter supported by S2' VMCAnalytic to be "Analysis of Equivalence: 1/5 or 2/10?" There is no record of a response by S2 to these comments.

On 4/12/15, S2 solicited feedback from R1, emailing a Word document version of her VMCAnalytic to R1. In this version, she used the suggested title of the corresponding book chapter. On 5/6/15, R1 responded that the VMCAnalytic was almost ready for publication, but recommended a few changes. She wrote that R2 had suggested that S2 modify the description of event five to include the role of the other girls who were with Meredith at the overhead as she explained her solution. She also questioned which rod was referenced by the researcher in event seven, suggesting that S2 explain which rod was referred to instead of using the non-specific term "it." She also recommended a few other minor wording edits: to add that two white rods would equal one red in length and refer to the researcher as "Researcher Carolyn Maher" instead of "the researcher Carolyn Maher." S2 responded to R1's feedback later that same day. She noted that she made all but one of the recommended edits. She disagreed that it was necessary to explain the role of the other girls in event five, since that had already been explained previously. On 5/8/15, R1 again recommended including the students' grade level in the title of the VMCAnalytic. This time, S2 did respond by updating the title as suggested. Thus, S2 took up most of R1's suggestions, enhancing the clarity of the VMCAnalytic and making it worthy of publication.

On 6/15/15, R1 recommended S2's VMCAnalytic for publication.

4.3 S3: Eighth-Grade Students Explore Surface Area and Volume Problems: The Role of Representations

4.3.1 Overview

S3 was a part-time student in the Ed.D program from 2011 to 2016. He was a lecturer at a large university in NJ and taught math since 2003, from 6^{th} grade through college level. He was introduced to the VMC during his first class at Rutgers where he watched videos from the VMC and was tasked with creating a VMCAnalytic for his final project. His very first VMCAnalytic was the first to get published on the VMC. When he began creating VMCAnalytics, there was very little training or guidance on the process; however, as he states, "the trials of the first groups to create analytics paved the way for the training and guidance that we currently give students."

S3 created the first version of his VMCAnalytic under study from a full length video on the VMC rather than from shorter video clips. At the time that he began working on his VMCAnalytic, the tool had not yet been updated to enable video streaming, so working from full length video was slower and more tedious. S3 therefore created the first version of his VMCAnalytic in the Rutgers WinLab since the high speed internet connection available there made working from full length video more tenable. As he worked at the WinLab, R4 interviewed S3, and a fellow classmate recorded observer notes. This process was videotaped and then transcribed for use in this study.

S3 created his VMCAnalytic as a support for his dissertation. The final version of his VMCAnalytic had nine events and was entitled “Eighth-Grade Students Explore Surface Area and Volume Problems: The Role of Representations.” In his overall description, S3 stated that the goal of his VMCAnalytic was to “examine how students use different representations to illustrate their developing understanding of the concepts of surface area and volume.” He then listed the types of representations that were depicted by the VMCAnalytic: manipulative/physical, written symbols, experiential, spoken language, and pictures and diagrams. Next, he contextualized the events of the VMCAnalytic by describing the larger study and stating that the events of the VMCAnalytic were all pulled from a single full length video of one session in which students use pen, paper, and Cuisenaire rods to work on four tasks related to surface area and volume:

1. Find the surface area of one rod.
2. Find the volume of one rod.
3. Find the volume of any number of stacked rods of a particular length.
4. Find the surface area of any number of stacked rods of a particular length.

The first of the nine events depicted the way in which the researcher introduced the first problem task to the students by invoking the representation of a stamp. In his description, S3 stressed the importance of the representation by noting that it drew on students’ prior knowledge, encouraged students to think of surface area as a two-dimensional measure, and allowed them to imagine the image produced by stamping. He also pointed out that, as the researcher introduced the task, Brian used the face of a white Cuisenaire rod to simulate using it as a stamp on another rod. In the next event, students determined that the surface area of the light green rod is 14. S3 highlighted the fact that they arrived at this conclusion by "carrying out the stamping process." In the third event, the researcher asked students if they could think of "a quick way" of determining the surface area of any rod. S3 noted that students then formulated a generalized formula, or a symbolic representation. In the fourth event, the researcher introduced the idea of volume, calling the white rod one unit and its volume one unit cubed, and asked students to calculate the volume of every other rod. In the fifth event, Romina defended her assertion that the volume of each rod equals (in value) to its length. S3 explained that Romina used both words and the Cuisenaire manipulatives as representations to explain her reasoning to Brian. In the following event, Michelle questioned Romina's formula, suggesting that the formula should include width and height, which in the case of the rods both equaled one. S3 highlighted that students began to "attend to the significance of expressing the appropriate dimensions." In the seventh event, the researcher discussed the formula of length = volume with Romina, noting that she couldn't mean that since the length is expressed in (linear) units while the volume is expressed in cubic units. S3 noted that the researcher encouraged students to attend to the unit in their formula. In the eighth event, the classroom teacher stacked two rods one of top of the other and Romina agreed that the volume is not three and that the formula must take width and height into account. In the last event, the group worked on finding formulas for both surface area and volume for a stack of rods of the same length.

As previously noted, S3 began working on his VMCAnalytic in the Rutgers GENI lab on 2/24/14 as R4 interviewed him. The first version of the VMCAnalytic that he created in the GENI lab included seven events. For that version, he did not create an overall description, but he did write brief descriptions for each event. While most of these descriptions summarized the events of the video, they were not explicitly connected to the theme of representations. Of the seven events, five were used in some form in the final version. The first event remained as the same first event in the final version. The second event of the first version was later split into two separate events and became events two and three in the final version. The third event of the original VMCAnalytic, too, was split, becoming the fourth and fifth events in the final version. The fourth event was split into three events and thus, the fourth event of the original VMCAnalytic became the basis for events six, seven, and eight in the final version. The fifth event of the original became the ninth and last event in the final version. The last two events of the original version were not included in the final version at all. When he concluded his session at the GENI lab, S3 stated, “Essentially, I have a full analytic except for the resolution.”

S3 began his work at the GENI lab by creating the first event of his VMCAnalytic. The video included in the first event, in which the first task was introduced, remained in the final version. S3 stated that he included the video for the first event since the researcher “is using the visual of a stamp and stamping.” He said that the video could later be replaced by summarizing it with text in a description if he felt that the VMCAnalytic was too long.

The second event included video in which students worked on finding the surface area of the light green rod using the Cuisenaire rods and found the surface area to be fourteen. The researcher asked for a formula to calculate the surface area for any rod, and students arrived at a formula. After working on the second event, S3 explained that the second event was included to demonstrate two representations, that of the student representing surface area using the rod manipulatives, and that of the student representing the formula for surface area "in the way he understood it" as "length times four times two." However, at this time, S3 only summarized the events of the video in the description and did not relate it to the theme of representations. As noted above, this event was later split and became events two and three in the final VMCAnalytic.

In the third event, the researcher asked students to find the volume of the other rods if the white rod was one cubic unit and students began working on a formula. S3 noted that what was interesting to him in the third event was how students first tried to come up with a formula and then tried to support it using the manipulatives. However, the formula the students initially used was incorrect. He pointed out that research finds that "symbolic representation is usually best when it's used last," but that "as students get older they want to use symbolic more." In the description for this event, S3 did relate the event to the overall purpose of the VMCAnalytic by writing, "Notice how Romina begins with a formula (symbolic) and then use the rods (manipulatives) to try to back up their assertions." This third event remained in the final version, but was the fourth event in that version.

After creating the fourth event, S3 summarized what happened in the video. In the fourth event, students initially decided to write that the formula for volume would be "length = volume". Then the researcher and teacher discussed it with the group, after which the group came up with the formula of v = l x w x h. This event was split into four events in the final version. R4 asked S3 how the event related to his theme of representations and whether he was focusing on the representation that the teacher used to encourage the students to reconsider their formula. S3 replied that he was focusing on the teacher's representation and that it was important since "he went to manipulatives and then came out with the formula which supports the idea that the symbolic should be later and not first." However, he did not include any reference to representations in his description at this time. In response to a question from R4, S3 said that he was keeping his events short because his experience of using a VMCAnalytic with longer events for professional development led him to realize that people lose focus when the events are too long and that he needs to stop "so we can kind of figure out what's happening." In this first version, S3 said that he was only describing what the event was about, but that as the VMCAnalytic evolved he would refine the events and "point out more minute details."

S3 then created the fifth event, which would become the last event in the final version. S3 said that students in this event worked on finding surface area and volume for a stack of rods. He commented that unlike previously, the students now first worked with the manipulatives and then tried to figure out a formula. R4 questioned S3 about how he would connect the event with his theme of representations and whether representations helped the students learn anything. S3 responded that using the manipulatives helped the students understand "where the formula comes from." However, at this time, the only change made by S3 was to summarize the video in his event description. S3 then stated that in his initial version of the VMCAnalytic, he had wanted to make sure to include anything that "tells the story of the activity" and had hence chosen to include too much rather than too little, but that in later iterations he might opt to refine the analytic by focusing more narrowly on the representations. R4 then questioned S3 as to how he would examine representations when students discussed the rods but did not note anything on paper. S3 replied that he would use the transcript to examine their talk since “talking about it is a type of representation.” R4 then asked if he thought of using screenshots from the video to show the representations built with the rods. S3 answered that he might do so and therefore was including video of “everything [he] might want to use” in this version, reiterating that he would cut it down later. When R4 then suggested that he could replace video with a text, S3 agreed and said that he might summarize the discussion with the researcher and teacher in text and then start with the subsequent video.

S3 then worked on the sixth event which did not end up being included in the final version. In his description, S3 noted that the students in the group needed to share something with the class. He noted that Michelle suggested an idea that the others in the group tested with the rods. R4 asked what role the representation played, and S3 noted that the students used the representations as confirmation of an idea and a way to convince others that an idea is correct. S3 then commented that he wanted to include a quote from a student who said that he doubts that that “there’s a formula that will satisfy everything” but that he did not know his name. R4 informed him that his name is Brian.

After working on the seventh event which was also excluded from the final version, S3 stated that the researcher questioned whether or not the surface area and volume would change if the rods were staggered “like a staircase.” Students then worked on that, but S3 said it was hard to hear their resolution, so he would check the transcript to determine whether or not they said something significant or used a representation that he would want to point out, but that if they did not, he would delete the event. As noted, this event was not included in the final version. He then noted that he would add another event as a culmination of the activity in which students share their work, but at this point S3 stopped working and responded to follow-up questions from R4.

In his responses to the follow-up questions, S3 revealed that he had noticed a place where he might want to add an event to portray Mike writing a formula for surface area and volume on the overhead. He then reiterated that he would refine his VMCAnalytic based on his writing, but that the VMCAnalytic would give him a framework for his writing and that it would be a good start for his dissertation, which would compare students' use of representations in elementary, middle, and high school.

4.3.2 First Cycle of Review

S3 received feedback on the first version of his VMCAnalytic on 11/18/14 from R1. In her comment, R1 wrote,

> What's especially powerful about this analytic is that the students begin with rods (concrete representation), are asked to "imagine" an attribute of the rod as a stamp, and build a formula --- that process is VERY important and needs to be followed in detail with the events…. More detail is needed for a dissertation analytic.

The first evidence of S3's continued work on the VMCAnalytic took place close to a full year after his session at the GENI lab. On 1/5/15, S3 updated his VMCAnalytic in the RUanalytic tool and submitted it for review. This version still did not have an overall description; however, S3 did update the event descriptions. In the first event, S3 added that the researcher began the discussion "using the cuisenaire rods, a manipulative representation" and cited "Lesh Post Behr 1987." In the second event, S3 also added a reference to representations, noting, "Students at this point move from the manipulative to a more symbolic representation, trying to create a formula." In the third event, S3 added a bit more detail to the his description of the video, noting that Mike expressed the formula for volume correctly “right in the beginning” but that he did not elaborate upon it to the group. In the fourth event, S3 clarified that when Romina stated that V=L x W x H, she was restating an idea raised by Michelle. In the fifth event, S3 added to his description, “Watch students...they begin to answer the question by using the manipulative first and counting. After they agree on the answer they then try to apply it to a formula. Students make much more progress by using the manipulative first and then the symbolic second.” By adding several references to the type of representations being used by students and explanations of how they progressed from using manipulatives to creating a formula, S3 took up R1’s recommendation to trace the process of how students advanced from using concrete representations to building formulae.

4.3.3 Second Cycle of Review

4.3.3.1 Part I

S3 submitted his VMCAnalytic for another round of review, and on 1/6/15, R1 responded with further comments that proved critical for the development of S3’s VMCAnalytic. In her comments, she made the following very important points. Those suggestions that were taken up in this round of review are **bolded**. Those that were taken up in later cycles of review are *italicized*.

1. *The events could be shorter (ex. event 5)*
2. **Text should be more detailed, describe or use actual quotes from students**
3. **Explicitly point out to viewers what to attend to in the video**
4. **The overall description should “pull together” the events**
5. **Explicitly point out to the viewer how students use representations to build the generalized formula**

6. Maybe create two analytics, one which focuses on surface area and the other on volume
7. **Note when a researcher or teacher intervenes**, *perhaps making it a separate event*
8. **Format carefully, specifically, the reference to Lesh**
9. Explain the manipulatives that are being used
10. **Situate the events within the context of the larger longitudinal study, include the grade level and topic, and reference Charlene's dissertation.**

R2, also provided crucial feedback on 1/7/15. Her comments provided the following guidance:

1. **In Event 1, instead of "just describing the action – which all can see," it is important to note that "stamping" created a two-dimensional representation of area**
2. **In Event 2, need to make clear what the task is that students are trying to solve**
3. **Need to use complete sentences in event 2**

R2 also questioned S3's interpretation of event 2. S3 had said that when students tried to come up with a quick way to calculate the surface area of any rod, they moved "from the manipulative to a more symbolic representation, trying to create a formula." R2 objected that perhaps the "notion of formula isn't yet what is happening" but that rather "students are calculating with the measurements that they found before to find the new surface area – rather than actually counting." This interpretation was not taken up by S3.

Interestingly, R2 made an astute observation about event three which did not affect the development of the VMCAnalytic during this cycle of review, but which was, perhaps, the catalyst for a deeper analysis of the video in later cycles of review. S3 had stated, “Romina also tries to begin with a formula (symbolic) L=V, and then use the rods (manipulatives) to try to back up her assertion.” R2 noted, “Seems to me - rather than arguing from a formula - that Romina is referring to the white rods as one unit of volume - lining them up and counting?” Although in this cycle of review S3 did not respond to this comment at all, and although on 2/27/15 he S3 responded, “Not sure what you mean by this,” in later revisions, S3 developed Romina’s argument more carefully.

S3 took up many of the reviewers’ suggestions in his subsequent updates to his VMCAnalytic. On 1/18/15, S3 began responding to the provided feedback by updating the VMCAnalytic in the RUanalytic tool and made several iterations of revisions before submitting the VMCAnalytic for review once again on 1/27/15. In this version, S3 added an overall description since he had not written one for the previous versions. The overall description in this version had many of the same components as the overall description in the final version although most of the ideas in the final version were rearranged and reworded. In this version, the overall description listed five types of representations and noted that the VMCAnalytic would examine how “students use these different representations… to better understand the concepts of surface area and volume.” It then situated the events of the VMCAnalytic within the context of the longitudinal study, noting the grade level of the students and the nature of the intervention in which the session took place. It then described seven tasks which students worked on in the session. Although in this version the last event dealt with students finding the surface area for a staggered stack of rods, that event was not included in the final version. Thus, in the final version, the last three tasks which dealt with finding the surface area of a staggered stack of rods were omitted from the overall description. In creating the overall description, S3 took up R1's suggestion to "pull together" the events of the VMCAnalytic in the overall description, to situate the events within the context of the larger study, and to include the grade level and topic.

S3 revamped his description of the events. In the first event, he took up R1's advice to correct his formatting, removing an incorrectly formatted reference to Lesh, Post, and Behr. This reference was later added to the overall description and was correctly cited. More importantly, he took up R1's suggestions to use more detailed text and explicitly explain to viewers what to attend to in the video. He did this by describing the events of the video in more detail and particularly by noting that Brian moved the white rod over another rod like a stamp. S3 also took up R1's suggestion to point out how students used representations to build the generalized formula by explaining that "the combination of these two representations [idea of a stamp and Cuisenaire rods] allows students a starting point for the upcoming activity on surface area." S3 then took up R2's advice to note that "stamping" created a two-dimensional representation of area. Thus, he stated that the "idea of stamping is a basic representation of surface area." As opposed to the final version, the description at this point only hinted at the importance of drawing on prior experience but did not explain it detail, noting briefly that "students, familiar with a stamp, can use their prior experience to represent what Researcher Maher is talking about."

In the second event, S3 modified his first sentence, making it more clear what task the students are trying to solve and making it a complete sentence. Thus he took up R2's advice to note the task students are solving and use complete sentences. S3 also added more detail about what occurred in the video and noted that students used the "stamping process" to calculate the surface area of the green rod. Thus, he also took up R1's suggestion to use more detail in his descriptions and point out how representations were used to build towards a generalized formula.

In the third, fourth, and fifth events, S3 took up R1's suggestion to include more detail and quotes in his event descriptions. In the third event he added an exchange which included a quotation from Michael demonstrating that Michael knew that the formula for volume is LxWxH. He also included dialogue in which Romina tried to back up her assertion that the formula would be V=L and Michael's disregard of the cubic unit. Additionally, in this event, S3 noted that students struggled to formulate a symbolic representation since they did not consider the unit of measurement. In the fourth event, he added a quote from the researcher in which she discussed the importance of attending to the unit of measurement. With this change, he took up R1's suggestions to include more detail, to use actual quotes, and to note researcher intervention. Lastly, in the fifth event, S3 again used more detail to describe the video. Thus, instead of saying that student "begin to answer the question by using the manipulative first and counting," he wrote, "Romina begins by first lining up white rods along the green stack and counting the length." He also described the task more clearly by specifying which rods were stacked. In addition, S3 elaborated on his assertion that students did not arrive at a formula because they did not engage with the manipulatives before trying to formulate a formula.

In this version, S3 also added a final eighth event as he had indicated earlier during his interview. This event, which was eventually deleted from the VMCAnalytic, depicted the researcher asking the students how they are progressing and asking them to write up their results. However, the session ended before the students were able to share their results with the class.

4.3.3.2 Part II

S3 submitted his updated VMCAnalytic for review on 1/27/15. R1 responded with comments in the RUanalytic tool later on that day on 1/27/15 and then again on 2/5/15. S3 had stated, "There are 5 categories of representations and many can be used in the learning of any mathematical topic. The five categories are manipulatives, written symbols, experiential, spoken language and pictures and diagrams (Lesh Post Beher 1987)." On 1/27/15, R1 noted that although it is okay to list references at the end of the description, S3 should not "assume that folks know the meaning of terms," for example, readers might not know what experiential representations are. She suggested just saying "what the categories that will be illustrated are." There were several typos in the descriptions and a couple of grammatical errors, so she also suggested putting the text through spell check and grammar check (since the tool did not include a spellcheck or grammar check feature). Furthermore, on 2/5/15, R1 suggested describing the tasks as "problems" instead of "questions" and to "restate the question earlier as a problem."

On 2/10/15, R2 also submitted comments through the RUanalytic tool. In addition to a minor grammatical correction in event two suggesting that S3 use the phrase "finding the surface area of each rod" rather than the surface area of "all the rods," she said that the fifth event was "confusing" since it was not clear what the students were working on.

On 2/27/15, S3 responded by agreeing that the video was confusing since the students were not staying on track. He questioned how to make the event clearer, asking if he should perhaps use "a different clip" instead. R2 also stated that the sixth event was not clear to her. She then commented that she had not noticed that the task of finding a formula to calculate the surface area for a stack of rods was ever solved in event six so that event seven in which students worked on finding the surface area of stack of staggered rods was a "huge leap." S3 responded that she was correct which is why he did not indicate that the task was solved. Both event six and seven were eventually deleted.

On 1/28/15 S3 also posted a comment related to his fifth event. He had noted in the event that students used the manipulative first, agreeing on a solution before attempting to create a formula. He had then stated that "students make much more progress by using the manipulative first and then the symbolic second." However, he commented that although he remembered reading such a theory, he could not find the source of the idea. Therefore, he asked if his reviewers could assist him in figuring out who had suggested the theory. There is no indication of response to this question, and this idea was removed in later versions of the VMCAnalytic.

S3 made edits to his VMCAnalytic in the RUanalytic tool on 2/8/15 and 2/27/15 in response to the comments by R1 and R2. He updated his overall description, fixing the typos and removing the reference to Lesh, Post, and Behr, and he fixed a grammatical error in the second event. With these changes he took up R1's recommendation to use spell check and grammar check. On 2/27/15, he emailed an updated version to both reviewers, adding more updates that were not included in the updates he made in the RUanalytic tool. In this version, he reinstated the reference to Lesh, Post, and Behr in the overall description and, in the second event, explained that the idea of stamping is an example of an experiential representation since "it draws on the student's prior experience of knowing what a stamp is and how it is used." With this change, S3 took up R1's indication that readers might not know the meaning of the term "experiential." In the overall description, he also referenced a dissertation by Marchese, as recommended by R1.

In the first event, he added to his explanation of stamping as a two dimensional representation of surface area, explaining, "For a quality understanding of surface area it is important that students are focused on surface area as a two dimensional concept," furthering his uptake of a comment by R2 in which she pointed out that it is important to note that stamping creates a two-dimensional representation of area. In the second event**,** S3 explained which members of the class were participants at the "feature table," taking up R1's recommendation from the previous cycle of review to situate the session within the context of the larger study. In the fifth event, taking up R2's comment that the video is unclear, he explicitly stated the task that the students were trying to solve. He then added a quote from Michelle and stated that "through the conversation you can see Romina and Michelle attempt to use the rods to speculate on a formula for surface area." Thus, he also took up R1's suggestions to quote students' words and to point out to readers what is important in the video.

4.3.4 Third Cycle of Review

On 2/27/15, S3 emailed R1 and R2 a Word document copy of his VMCAnalytic which included the VMCAnalytic descriptions and transcripts of the video included in the events. On 3/1/15, R1 responded to S3 with an edited Word document along with her comments. R1 edited the text of the VMCAnalytic, improving its accuracy and clarity, including changing the term “all of the rods” to “each of the rods” as R2 had previously suggested. She commented that S3 should refer to the VMCAnalytics as such instead of using the shorter term “analytic” since the term “analytic” has a special meaning in the learning sciences. Regarding the first event, she suggested that the image of a stamp might be what Goldin refers to as an imagistic representation while “making the stamp with the white rod” is experiential.

In the third event, R1 made several important observations. She said it was unclear to her why the events were partitioned as they were and suggested partitioning the third event into more than one event so that the video could be described in more detail, “pointing to the representations that the particular students are using.” She then noted that Michael’s mention of the formula “length times width times height” may be a representation, asking how S3 would classify it. She then brought up an important observation. S3 had noted that students struggled to create a formula to calculate volume since they did not understand the “importance of the cube unit.” R1 commented:

> Seems to me to a different idea, that is, the representation of square and cubic unit… Not all representations are adequate. They can represent square unit with the stamp; cubic unit with unit cube, but cannot distinguish the two in their symbolic representation and this seems to me to be important and worthy of an event in itself…

R1 emailed her edited version of the document to S3 on 3/1/15, suggesting in the email that S3 consider including representations discussed by Goldin, such as imagistic representations. This echoed her comment in the document which noted that the image of a stamp is an imagistic representation. She also commented that she would like to “schedule a time to sit together and work through” the VMCAnalytic with S3.

R2 also edited the document and made comments, emailing it to S3 on 3/8/15. She, too, edited the text to make it clearer and more accurate. However, since R1 had emailed her edited version to R1 without copying R2, R2's edits were made to the document which S3 sent, not accounting for the changes which R1 made to the VMCAnalytic. Thus, many of her changes overlapped with those of R1. In addition to her edits, R2 made several important comments. She said that event five was unclear, asking S3 if he had any ideas about how to make it clearer. She also noted that the seventh and eighth events "offer very little" to the analytic, suggesting that the VMCAnalytic end after the sixth event.

On 3/10/15, S3 split the second event into two distinct events, which became events two and three in the final VMCAnalytic. Whereas the initial event had been a bit over two minutes long, the new events were about one minute long each. However, at this time, the description of each event was identical to the original description.

About half a year later, S3 continued his work on the VMCAnalytic. S3 created an updated Word document, incorporating the text changes recommended by both R1 and R2 in their respective Word documents, splitting the event descriptions appropriately for events two and three, and adding some other changes. In the first event, S3 added that "externally this idea of stamping is an experiential representation of surface area" but that "internally this is also an imagistic representation, where the students must 'imagine' a stamp," citing Goldin and Kaput. He then elaborated on the idea of an imagistic representation. Thus, he took up R1's suggestion to consider the mental image of a stamp as an imagistic representation.

The second event had previously been split into two events in the RUanalytic tool. Now, S3 split what had been the description for event two, applying the text relevant to the first part of the video to the description of event two, and using the text relevant to the second part of the video for the description of event three. In the fourth event (which in the previous version was event three), S3 added:

> However, the students did not yet appreciate the importance of in those representations of units [two dimensional stamp representing square unit and white cube representing cubic unit] and failed to translate them to the symbolic representation of a formula. So not only are the representations important, but students must also have the ability to move between representations to gain understanding (Lesh, Post, & Behr, 1987; Goldin, 2001; NCTM, 2000).

With this, he took up R1's comment that students could not "distinguish the two [square unit and cubic unit] in their symbolic representation," attempting to explain why students struggled with creating a formula for measurement of volume. He also took up R1's observation that Michael's use of the formula "length times width times height" was a symbolic representation, noting as such in his description.

In the sixth event (which in the previous version was event five), S3 removed the statement for which he had not found a reference: "Students were making more progress by exploring the manipulative first and then the symbolic of trying to come up with a formula second."

4.3.5 Fourth Cycle of Review

R1 responded with feedback in a Word document containing edits and comments which she emailed to S3 on 9/9/15. She asserted that S3 must define "imagistic" in the first event as it is described by Goldin and Kaput. She also edited his description of how the image of a stamp is an imagistic representation, improving the clarity of the explanation. In the third event, R1 added to S3's description to note that the formula expressed by the students was generalized to find the surface area of any rod. In the fourth event, S3 had stated that Michael did not elaborate upon his statement that the formula for volume is "length times width times height." R1 commented that S3 should not state "what a student does NOT do."

As quoted above, in the fourth event, S3 had stated, "…not only are the representations important, but students must also have the ability to move between representations to gain understanding." R1 commented, "The representations are for different units – square and cubic. So, they are not moving between representations of the same concept. Rather, confusion seems to be between two different ideas – square and cubic units." In the body of her email, R1 commented that event six was too long. As she had in her first round of comments, she again suggested including "the particular and important quotes that direct the reader to pay attention to certain student actions" and added that he should "focus on the particular moments that show representations AND the building of a solution."

R2 also submitted comments in the Word document. She suggested splitting both the fourth and fifth events into two separate events and to delete some irrelevant video footage from the fifth event. She noted in the transcript the particular sections which should constitute the new events.

On 9/21/15, S3 emailed the latest version of his VMCAnalytic. In this version, he incorporated the edits R1 had made. He also removed the reference to Marchese's dissertation. Additionally, in the fourth event, he removed the statement that Michael did not elaborate on his formula, taking up R1 suggestion not to state what a student does not do. He also clarified that "students must also have the ability to fully understand all aspects of the representation to gain better understanding of the concept," instead of stating that they must be able to “move between representations,” taking up R1’s insight that students are not “moving between representations of the same concept” but rather confusing the different ideas of square and cubic units. He then noted where he would split the fifth event into two separate events at the point where the researcher returned to the table and engaged the students in a discussion about the formula for volume.

On 9/23/15, S3 emailed another version, splitting the fifth event into two events and removing video of off-topic discussions from the event. He also added a description for the new sixth event. In the description, he detailed the discussion between the researcher and students about their formula for volume, explaining events of the video which had not been described hitherto. Additionally, he noted that the researcher stressed the difference that units create and that “this is a big leap for students because unlike with surface area, volume is a three dimensional representation….” Thus, he took up R2’s suggestion to split the event and remove irrelevant video footage and R1’s earlier suggestions to describe the events in more detail and point out why those events are important.

Again on 10/7/15, S3 emailed another updated version, inviting feedback from his reviewers. In this version, he updated his overall description, re-ordering ideas and revising sentences, improving the clarity of the overall description. He also added an overall title, “Student Use of Representations in Solving Surface Area and Volume Problems.” In the third event, he replaced a paraphrase of the researcher with a direct quote, taking up R1’s advice to use quotes.

S3 made several enhancements to the fourth event, improving the description of the fourth event by adding a much more comprehensive description of the events of the video. First, instead of spreading out quotations from the transcript throughout his description, he presented the transcript in its entirety as a single piece, including more of the student dialogue. This made the description easier to follow. Second, he replaced his statement that “Romina suggests a formula (symbolic) L=V, and then uses the rods (manipulatives) to try to back up her assertion” with a lengthier explanation of how Romina used representations in her argument. He stated:

> Romina offers the idea that length equals volume. She not only explains what she means (spoken words) but she takes a yellow rod (manipulative/physical), and lines up five white rods next to it to show that the yellow rod’s volume is five cube units, which is the same as the length of the yellow rod. Here we see Romina moving between two representations. She is verbally explaining what she means by L=V and also using the manipulatives to illustrate her words. While if you were to only examine Romina’s words her explanation is difficult to follow because her language is imprecise. However with the added illustration of the manipulative she is able to get her point across to the others in the group, as evidenced by Brian’s last statement that he understands where she is going.

He thus took up R1’s suggestions from the previous cycle of review to describe what was then event three in more detail and to point “to the representations that the particular students are using.” Third, S3 removed his statements that “students struggle… as they attempt to create a symbolic notation for volume,” though leaving in the explanation of how the different units of measurement created confusion. Fourth, he shortened the length of the event. R2 had suggested either removing some video completely or creating a separate event from it. Although S3 did not remove the exact segment of video suggested by R2, he did partially take up her recommendation by shortening the event. All these changes together improved the clarity and coherence of the fourth event.

S3 updated the sixth event as well, splitting it yet again so that the teacher’s intervention constituted a separate event. He also added a quote from Romina in which she explained to the researcher that the volume of the red rod is two units cubed when the white rod is considered one cubic unit. By including an additional quote, S3 may have been taking up R1's recommendation in the second cycle of review to use actual quotes from students. Additionally, when quoting the researcher who referred to the rods in the video as "this" rod, S3 added parentheses to clarify which rods the researcher was referring to.

In the seventh event, S3 described the teacher's interaction with the students in much greater detail than he had previously. In creating a separate event for the teacher's intervention and describing it in more detail, S3 was perhaps taking up a comment from R1 in the second cycle of review in which she recommended noting when a researcher or teacher intervenes, perhaps making it a separate event.

S3 also took up R1's comment that the sixth event was too long. In this version, the sixth event was now the eighth event. S3 shortened the eighth event from about two minutes to about one minute long, keeping the video in which students found the surface area for a stack of three green rods, but removing video in which students tried to find a generalized formula for the surface area of a stack of rods. With this, he took up R1 comment that the event was too long.

S3 then removed the last two events (events ten and eleven), taking up R2's comment from the third cycle in which she stated that the last two events (which had been events seven and eight) contribute very little to the VMCAnalytic.

4.3.6 Fifth Cycle of Review

Both R1 and R2 responded to S3's updates with comments and edits on 10/23/15. R1 edited the overall description and the descriptions of events one, three, four, five, six, and seven. These edits greatly improved the clarity of these descriptions.

R1 also made several important comments in the fourth event. She suggested quoting Brian who said that the volume of the light green rod would be “three units cubed” since he was “attentive to the units” for volume while using “natural language.” She then observed that Michael was “attending to length” when he stated that the length of the yellow rod is five and that Romina took up Michael’s comment when she used “ordinary language” to explain that the volume of the yellow rod is “five cubes.” R1 noted that Brian responded that he “knows what [Romina is] doing” since Romina “does attend to units, using her ordinary language.” R1 then recommended including students’ “exact words… as quotes” in the event descriptions so that readers do not miss what the students are doing even though the “students are NOT using the math register but they are using their own natural language.” She also pointed out, that while Romina ignored the units in her formula, Brian did “pay attention” to units.

R1 also enhanced the fifth event by explicitly noting why the event was important and how it related to the overall story since students were starting to “attend to the significance of expressing the appropriate dimensions” when Michelle offered that the formula for volume should account for width and height in addition to length.

R2 made significant edits and comments as well. She edited references to “all the rods,” modifying them to “each of the rods” in events four and five, thus making a modification she had suggested in the second round of review but which had not been taken up. She made other significant edits to the event descriptions in events four, eight, and nine, improving their clarity. She also suggested being clearer about the point in the fourth event where S3 stated that “students did not yet appreciate the importance in those representations of units and failed to translate them to the symbolic representation of a formula." Importantly, she noted, that the transition between events seven and eight needed to be improved. She stated that there "needs to be… more description of what happened" between the events and that the description in the eighth event should explicitly inform readers of what students worked on in both the seventh and eighth events. She asserted that S3 should explicitly point out that Brian was trying to write the formula. Then, notably, S3 observed:

> The big idea in this event is Michelle who successfully articulates that there are 8 "sides" - three on the front – three on the back – and the top and bottom. Then she counts the 6 square units that are on the two ends to arrive at 30 square units of area – show this – describe it in your event description – and then stop.

She then noted in the transcript where she thought was an appropriate place to end the event since nothing significant occurred subsequently.

R2 asserted that the description of the ninth event should be very clear and that "the formula that emerges… is what we are after." She then made another very important observation that the event "only makes sense if we assume…that they have moved from three to four light green rods – so that they have 10 sides… plus 8," urging S3 to "check it out."

S3 responded to the comments with a new version on 11/3/15. He accepted the edits made by R1 and R2 in the overall and event descriptions. He then split the fourth event, creating two events from the video. With this, he may have taken up R1's suggestion from the third cycle of review to partition what at that point was the third event. In the fourth event, he quoted the researcher as she introduced the task of finding the volume of each of the rods. In the fifth event, he took up R1's recommendation to include students' "exact words… as quotes" in the event descriptions so that readers do not miss what the students are doing even though they are using natural language. Thus, he removed the lengthy transcript of student conversation about determining the formula, including only student quotes that were appropriate to the narrative and integrating them into the description. He then further took up R1's analysis of the event, quoting Brian who said that the volume of the light green rod is "three units cubed" and noting that Romina took up Michael's comment in her response that the volume of the yellow rod is "five cubes." He then stated, "Because Romina's model does take units into account Brian responds, 'Okay. I know what you're doing.'" With this, S3 took up R1's observation that Brian knew what Romina was doing since Romina did "attend to units." He also took up R1's analysis when he stated that Romina's words alone were "difficult to follow because she is using her conventional language" but that by using the manipulatives she was able to "take units into account."

S3 also took up R2's recommendations. In the ninth event (previously the eighth), S3 added a transition by reminding readers that students worked on finding a formula for volume in the previous event. He then clarified what occurred after the previous event but before the start of the ninth event and explained that the task of the ninth event was to find the surface area for a stack of three light green rods. Thus, he took up R2's recommendations to improve the transition between those events and to explicitly inform readers of the tasks which students worked on in each of the events. Then, taking up R2's observation that it is important that "Brian is trying to write the formula," S3 explicitly noted that Brian tried to write the formula. More importantly, S3 took up R2's recommendation to point out that Michelle articulated that there were eight sides "showing" which had length of three plus six more units on the two ends. Thus, he wrote that "Michelle is using the rod model and counting the open faces showing in the model" and then quoted Michelle as she calculated the surface area. He also took up R2's recommendation to end the event after Michelle's calculation since what followed did not add to the event.

S3 also took up R2's assertion that the description of the ninth event should be very clear and that "the formula that emerges… is what we are after." Accordingly, in what was now the tenth event, S3 shortened the event to focus solely on the emergence of the formula as expressed by Michelle. He removed the last minute of video from the event, summarizing it instead in the description.

In a version which S3 emailed to his reviewers later that same day on 11/3/15, S3 further modified the tenth event, clarifying Michelle's quote and removing the summary of events which followed the event. However, on 11/6/15, S3 updated the VMCAnalytic in the RUanalytic tool; in this version, he deleted the tenth event completely. This appears to have been done in error since there is no mention of this change in his correspondence with reviewers, and the task list in his overall description includes mention of the task worked on in this event. Moreover, without this event, the VMCAnalytic does not have an appropriate ending.

On 11/11/15 and 11/13/15 R1 emailed S3 with a couple of small corrections, remarking that when those small changes will have been made, R1 would recommend the VMCAnalytic for publication. These changes included a few typos and the recommendation to remove the last two tasks, which involved a staggered stack of rods from the list of tasks in the overall description since the corresponding events were no longer included in his VMCAnalytic. As mentioned in the above paragraph, though, the fourth task of finding the surface area of any number of stacked rods with a particular length which had been included in the tenth event remained in the description although the event itself was deleted.

S3 made the suggested changes on 11/13/15, and on 11/15/15, R1 recommended the VMCAnalytic for publication. On 11/17/15, the VMCAnalytic was published.

4.4 S4: Ariel Constructing Linear Equations for “Guess My Rule” and the “Ladder” Problems

4.4.1 Overview

S4 was a student in the Rutgers M.Ed. program from 2014 through 2016. She was a high- school mathematics teacher who had eight years of teaching experience when she created her VMCAnalytic under study, with experience teaching math in grades 6-12. She first learned of the VMC and VMCAnalytics while enrolled in a graduate course at Rutgers with Dr. Alston. Although she created the VMCAnalytic as a project for a course, she stated that she “created the VMCAnalytic… because I wanted to have it published for others to use” and that she “enjoyed the research.” She then continued to work on the VMCAnalytic during a second course at Rutgers. She stated that the purpose of her VMCAnalytic was “to illustrate a student’s (Ariel) reasoning and engagement in problem solving pertaining to linear functions, as well as to illustrate Common Core State Standards for Mathematical Practice.”

S4’s VMCAnalytic was entitled “Ariel Constructing Linear Equations for ‘Guess My Rule’ and the ‘Ladder’ Problems.” The final version of her VMCAnalytic contained ten events and ran close to 17 minutes (16:53). This subject was unique in that four people reviewed her VMCAnalytic, two faculty members, one graduate student, and one fellow Master’s student.

In her overall description, S4 stated that the VMCAnalytic focused on one particular student, Ariel, as he worked on several problems related to linear functions. She then situated the events of the VMCAnalytic within the context of the larger longitudinal study by describing the Informal Mathematics Learning (IML) project, the after school learning project for middle school students in which Ariel participated. S4 stated that the VMCAnalytic provided "evidence of student reasoning" and Ariel's engagement with four Common Core State Standards (CCSS) for Mathematical Practice. The four practices, practice numbers 1, 4, 7, and 8, highlighted by the VMCAnalytic were:

1. Make sense of problems and persevere in solving them (practice 1).
2. Model with mathematics (practice 4).
3. Look for and make use of structure (practice 7).
4. Look for and express regularity in repeated reasoning (practice 8).

S4 then described the tasks on which Ariel worked in the events portrayed by the VMCAnalytic. The first activity was "Guess My Rule," a task in which coordinate pairs of numbers were presented in a truth table and students were tasked with figuring out the linear equation or "rule" which translated each number to its pair. The second task was to formulate the linear equation or method for determining the number of rods which would be needed to form a "ladder" of rods of a given size. The last activity portrayed by the VMCAnalytic is an interview with Ariel in which he discussed the ladder activity.

First, S4 outlined the theoretical perspective that underlay the VMCAnalytic which was presented in Davis's (1992) "Emerging New View of Mathematics Education." In this view, students worked on tasks before learning the underlying mathematical concepts instead of first learning the mathematical ideas and afterwards applying them. S4 asserted that by applying this "new view" approach, as demonstrated by the researchers in the VMCAnalytic, students can not only progress in their fluency of the Common Core State Standards for Mathematical Content, but also engage in the Common Core State Standards for Mathematical Practice. S4 cited Davis also as the originator of both the "Guess My Rule" task as well as the "Ladders" problem. S4 then provided the problem statements on which students worked in the VMCAnalytic and noted details about the IML project leaders and funding.

The final version of the VMCAnalytic contained ten events. The first event portrayed researcher Powell as he introduced the "Guess My Rule" task to the students in the form of a game. In the second event, Ariel offered a "rule" to solve the first truth table. S4 pointed out that Ariel engaged in the seventh and eighth mathematical practices by explaining and using a pattern to find the rule. She also pointed out that researcher Powell labeled the pair of numbers with a box and triangle and noted that this is an example of "Cognitive Simplicity," citing Alston and Davis (1996) who explained "Cognitive Simplicity" as the use of symbols that are meaningful to children. The third event depicted Ariel and his partner James as they worked on the second truth table problem. In this event, S4 noted that Ariel engaged in the first and seventh practices as he asserted that the problem is "the same thing" as the first since he "considers analogous problems" and "makes use of structure." She also drew the readers' attention to fact that the box and triangle were replaced with an x and y on the worksheet students were using. In the fourth event, Ariel explained his rule to researcher Powell and S4 asserted that Ariel engaged in practices one, seven, and eight as he applied his rule to the numbers in the truth table. She also noted that as he justified his rule to researcher Powell, Ariel noticed another pattern, namely that the y values had a constant difference of two.

Event five introduced the next problem highlighted by the VMCAnalytic. In this event, researcher Francisco introduced the Ladder problem to Ariel and James. However, in this problem, the researcher did not suggest building a truth table. S4 noted that the Ladder problem "supports the theme of 'Building and Generalizing From Simple Ideas' (Alston and Davis, 1996, p. 11)" which "refers to situations that present obvious patterns… often modeled with concrete materials, from which students can explore… mathematical rules." In the sixth event, Ariel calculated the number of rods in a ladder with ten rungs by counting the number of rods used in a ladder of five rungs and doubling that number. Although his solution of 34 was incorrect, S4 asserted that Ariel engaged in the eighth mathematical practice since his method "involves generalization and a short-cut calculation." In the seventh event, Ariel built a ladder with ten rungs to justify his solution of 34, and S4 noted that he thus engaged in the fourth mathematical practice of building models. Ariel realized that the number of rods in a ladder of ten rungs is 32 and then modified his original solution, explaining that the ladder of ten is two less than double the number of rods of a ladder of five. The eighth event portrayed Ariel's explanation of a composite rule for determining the number of rods needed to created ladders with either an even or an odd number of rungs. S4 noted that although his rule is "long and not elegant," it is "mathematically… equivalent to the much simpler rule of 'multiply the number of steps by three and add two.'" In the ninth event, Ariel wrote his rule for how to calculate the number of rods needed to create a ladder with an odd number of steps. S4 asserted that Ariel thus demonstrated mathematical understanding according to the CCSS which states, “One hallmark of mathematical understanding is the ability to justify, in a way appropriate to the student’s mathematical maturity, why a particular mathematical statement is true or where a mathematical rule comes from” (CCSS, 2010, p. 4). In the last event, researcher Arias interviewed Ariel one year after he worked on the Ladder problem. This time, Ariel constructed a table of values, labeling them x and y and writing the rule as y = 3x+2. He then justified his rule in several ways. He showed that specific values from his table worked with the rule, demonstrated with the Cuisenaire rods why the rule worked, and modeled the rule on a graph. S4 noted that in this event, Ariel demonstrated all of the four mathematical practices highlighted by the VMCAnalytic as well as demonstrated “how a mathematics problem can link various algebra concepts.”

4.4.2 First Cycle of Review

S4 created her first version of the VMCAnalytic, entitled “Ariel & The ‘Guess My Rule’ and ‘Ladder’ Problems: An Illustration of Common Core State Standards For Mathematical Practice” on 3/23/14 which she submitted for review on 10/6/14. This version contained many of the same elements as the final version; however, there were several notable differences between the first version and final version:

1. This version began with a lengthy quote from the CCSS about “students who lack understanding of a topic” who “may rely on procedures too heavily” and “be less likely to consider analogous problems, represent problems coherently, justify conclusions… or deviate from a known procedure to find a shortcut.” It stated that “In short, a lack of understanding effectively prevents a student from engaging in

the mathematical practices. (Common Core State Standards Initiative [CCSSI], p. 8)” This quote was omitted from the final version.

2. In the final version, one of the purposes of the VMCAnalytic was stated as, “This analytic provides evidence of student reasoning as Ariel explores different approaches to solving problems that link various algebraic concepts.” However, in the initial version, this purpose was stated as: “This analytic will show student reasoning and problem solving approaches through activities that link multiple algebra concepts which illustrate specific Common Core State Standards (CCSS) For Mathematical Practice.”
3. The first version stated, “The heuristic design of the problems that Ariel is seen working on in this analytic allows him to build his own understanding. Both the ‘Guess My Rule’ and ‘Ladder’ problems encourage Ariel to learn, discover, and solve by experimenting, and evaluating possible solutions by trial-and-error.” This statement was removed in the final version.
4. The first version stated, “Ariel’s perseverance in problem solving and his willingness to accept new challenges (CCSS Practice Standard One) is seen repeatedly throughout this analytic.” This statement was omitted in the final version.
5. The final version attributed the “Guess My Rule” and “Ladder” tasks to Dr. Robert B. Davis and noted details about the IML project leaders and funding which were not present in the first version.
6. Many of the paragraphs and ideas were rearranged between this version and the final version. In this first version, the practices illustrated by Ariel’s work were

listed after the problem statements, followed by statements that were later removed about Ariel's perseverance and the heuristic design of the problems, and finally by the discussion about Davis's "New View."

Thus, in the first version, in addition to highlighting engagement in specific CCSS practices, the stated purposes of the VMCAnalytic were also to demonstrate how through working on problems with a specific "heuristic design," Ariel built understanding of various algebraic concepts by "experimenting, and evaluating possible solutions by trial-and-error," and to "provide evidence of student reasoning as Ariel explores different approaches to solving problems that link various algebraic concepts." The focus of the VMCAnalytic was narrowed in the final version to highlight Ariel's engagement in specific CCSS practices as he solved problems which linked multiple algebraic concepts.

In contrast to the final version which has ten events, the first version contained only nine events. The first version did not include what became the eighth event in the final version. This event was added during the first round of review. There were also significant differences between many of the descriptions and titles created in the first version and those that appeared the final version. Many of these changes were in line with the more focused purpose of the final version as opposed to the first version. The description of the first event in the first version included a description of various algebraic ideas that are inherent in the activity, which was not included in the final version. Also, in the first version of the fifth event, S4 stressed that no formal procedure was given to the students and that using the Cuisenaire rods could "empower Ariel to create both a mental image and model of the task."

Additionally, in the first version, in the first event, S4 did not describe the rules of the "Guess My Rule" activity. In the fourth event, although S4 noted that Ariel engaged in the first, seventh and eighth practices, she did not explain that he demonstrated these practices as applied his rule to the x-values in the truth table. In the fifth event, as well, less detail was used to describe the events of the video to explaining the "Ladder" problem and to describe Ariel's and James's work on the problem. In the first version of seventh event, S4 stressed how Ariel's attempt to arrive at the solution of 32 embodied the fourth CCSS mathematical practice; however, in the final version, this description was removed. Instead, in the final version, S4 wrote that Ariel "is more interested in deriving 32 rods, rather than understand why his original method involving proportional reasoning did not work." The description of the last event was very different than that which appeared in the final version, with this version containing far less detail about the video than the last version.

S4 received feedback regarding the first version of her VMCAnalytic from several reviewers. On 10/6/14, R2 responded by submitting comments via the RUanalytic commenting tool. She questioned whether the first part of the overall description, apparently a reference to the quote from the CCSS, was necessary, but did not elaborate on why she may have thought it was not. Later that day, S4 responded, that "every word" was indeed necessary. P1 disagreed on 10/19/14, observing, "I see where the first section could be left out without taking away from the analytic." She then asked how else S4 might be able to point out that Ariel was "working thoughtfully and not relying on procedures." On 10/27/14, S4 explained that she had included the quote since the VMCAnalytic showed Ariel engaged in the CCSS for Mathematical Practice. On

10/29/14, R2 responded that she could substitute the quote with an explanation that Ariel consistently tried to "make sense of the problems." In the subsequent version, R2 deleted the quote.

Importantly, R2 suggested that S4 include an event to depict Ariel's rule for calculating the number of rods in a ladder with an even number of rungs. On 10/19/14, S4 took up R2's recommendation, noting, "I did add an event as [R2] suggested to show Ariel's Rule for Even Numbers." Indeed, S4 added a new event to depict Ariel's rule for calculating the number of steps in a ladder with an even number of rungs.

On 10/19/14, P1 noted that it would be important to state Ariel's grade level. R2 agreed, but S4 responded that she had already noted it in the description, and thus, this comment did not ultimately impact the VMCAnalytic.

On 10/19/14, S4 requested guidance in titling her events, asking whether she should title them all consistently beginning with "Ariel," presumably followed by what he did in the event. This comment was taken up by reviewers in their comments on the individual events, which will be discussed below.

R2 questioned whether her overall title could be improved. On 10/27/14, S4 suggested titling the VMCAnalytic "Ariel's Rules: An Illustration of Common Core Standards For Mathematical Practice." R2 responded that she would think about as she re-watched the VMCAnalytic, suggesting that perhaps they include a reference to Ariel "constructing rules" or "trying to make sense of the problem." On 11/2/14, S4 suggested the title, "Ariel's Rules: Engagement in Common Core Standards for Mathematical Practice." In an email to S4 on 11/7/14, R2 suggested the title, "Ariel Constructing Linear

Equations for ‘Guess My Rule’ and the ‘Ladder’ Problems.” S4 took up R2’s suggestion and used the title she suggested.

On 10/29/14, R4 questioned S4 about the main purpose of the VMCAnalytic. She asked how the lengthy quote at the beginning of the description was related to its overall purpose. She questioned if the VMCAnalytic intended to show that Ariel developed a strong understanding of the topic and could therefore engage in the CCSS mathematical practices, or whether the main idea was to demonstrate his engagement in those practices. She suggested that if the purpose was the former, then S4 should be specific about what emerged as evidence of his understanding. However, if the purpose was the latter, she asked if S4 was attempting to show that engagement in the practices helped Ariel build understanding or just to demonstrate instances in his engagement in those practices. She also suggested moving the last two paragraphs to the beginning of the VMCAnalytic so that the description would concentrate on the theoretical framework in a unified manner and then outline the events that would demonstrate the theoretical concept.

Later that same day, S4 responded that originally she had intended two different purposes for the VMCAnalytic, to demonstrate Ariel’s engagement in the CCSS mathematical practices, and to “highlight problems that promoted algebraic reasoning.” However, she explained that she had changed the purpose of the VMCAnalytic to only illustrate four CCSS mathematical practices as Ariel worked on the tasks. She confirmed that it was not her intention to demonstrate that Ariel built understanding by engaging those practices, but questioned whether that was an idea that she should incorporate. S4 noted that she included the lengthy quote since “the quote talks directly about the CCSS Practices,” but added that if it was unnecessary she would remove it.

Later that day, R4 responded that she had thought the intention was to show that Ariel's engagement in the practices was possible since he developed a deep understanding, but if that was not the intention, she thought the quote was confusing and should be removed. Instead, the description should explicitly say that the purpose of the VMCAnalytic was to demonstrate a student's engagement in four practice standards. Additionally, she suggested that the last paragraph should address all four standards instead of only mentioning the practice of perseverance.

The following day, on 10/30/14, R2 took up the thread of the conversation, suggesting that instead of writing that the VMCAnalytic would "show student reasoning and problem solving approaches through activities that link multiple algebra concepts which illustrate specific Common Core State Standards (CCSS) For Mathematical Practice," it might be better to say, "This analytic provides evidence of student reasoning as Ariel explores different approaches to solving problems that link various algebraic concepts. The student's engagement in the problems also illustrates specific CCSS ..."

On 11/2/14, S4 took up these suggestions by saying "I love your feedback" and that she would reword the VMCAnalytic description. In her subsequent version, S4 made the following changes, taking up the reviewers' suggestions:

1. S4 moved the paragraphs which listed the practices that would be illustrated by the VMCAnalytic and described the "Emerging New View of Mathematics Education" up to precede the description of tasks as recommended by R4.
2. S4 deleted the sentence which spoke about Ariel's perseverance as suggested by R4.

3. S4 took up R2's recommendation and changed the statement of purpose to: "This analytic provides evidence of student reasoning as Ariel explores different approaches to solving problems that link various algebraic concepts. Ariel's engagement in the problems posed by the researchers in this analytic illustrates four Common Core State Standards (CCSS) For Mathematical Practice..."

S4 also received feedback from R1 on 11/4/14. R1 recommended that she remove or move the reference to literature which describes the activities in which Ariel engaged. She stated that if S4 felt a need to reference the literature, the citation should not be in first sentence in which she describes the activity. On 11/9/14, S4 responded that she could remove the reference and indeed did remove it in the subsequent version.

S4 also received feedback on the events of her VMCAnalytic relating both to their titles and their descriptions.

R2 took up S4's question about using Ariel's name in the titles of her events. She recommended removing the reference to Ariel in the title of the second event since he was not the only one trying to discern a pattern in the truth table. S4 took up this comment, saying, "I like your title" and changed the title from "Ariel Sees a Pattern" to "Making Sense of Patterns."

R2 also recommended modifying the title of the third event, explaining that "it seems to me that the big idea is their recognizing that this pattern is similar to the one before" and asking if this idea could be captured by the title. S4 took up this suggestion on 10/29/14 by asking if a more fitting title might be, "Problem Two: 'It's the same!'" R2 responded that this title was better, but perhaps to word it, ""Problem Two: It's the Same Thing!" On 11/9/14, S4 took up this comment by responding that she had modified the title accordingly. Thus, she changed the title of the event from “Ariel Writes a Rule” to “Problem 2: ‘It’s the same thing!’”

Regarding the title of the fourth event, R2 commented, “Seems to me that this title is good - Ariel’s name here makes sense to me.”

However, regarding the seventh event, R2 recommended changing the title, “Modeling a Solution & Identifying an Error,” since she felt that the “big idea in this good event is Ariel’s attempt to reconcile the obvious contradiction between the number of rods that he has counted and his firm belief that his proportional procedure should work. He is not trying to figure out why - just to make it work.” She then recommended trying to capture this idea better in the title. On 10/29/14, S4 responded that she would have to think about how to do that, following up on 11/9/14 by stating that she had made the change. Her new title for the event was “Going From 34 to 32.”

In the ninth event, R2 recommended changing the title from “Ariel’s Rule for an ‘Odd Numbers’” to “Ariel’s Rule for a Ladder with an Odd Number of Steps.” S4 took up that comment, responding on 11/16/14 that she had implemented the change, and indeed, this change was made in the subsequent version.

S4 received additional feedback regarding her event descriptions. Regarding the first event, R2 recommended combining her first two sentences to make it more concise. On 10/27/14, S4 took up this comment by responding that she had implemented the change. In reality, though, R2 merely removed the second sentence in which she had stated, “Students are not given a formal procedure, rather an explanation on how to play the game.”

On 11/4/14 R1 recommended removing a reference to work describing the activity, as she had recommended doing in the overall description. However, R2 took up this comment and suggested that S4 remove the quote completely and instead use her own words to state that "the task involves thinking about linear functions, etc. - or something like that." S4 responded on 11/9/14 that she had implemented the change, taking up R2's recommendation by substituting the quote with, "This game invites the seventh-grade students to think about linear functions."

On 10/27/14, P1 made a suggestion about the fifth event about rewording one sentence to make it grammatically correct. S4 took up her suggestion, responding later that day that it was a "great point" and that she had made the correction. As P1 suggested, instead of writing that "no formal procedure or mathematical ideas on how to solve the problem is given," she wrote, "no formal procedure on how to solve the problem is given."

Also in the fifth event, S4 had stated that the fact that the researcher introduced the "Ladder" problem with Cuisenaire rods could "empower Ariel to create both a mental image and model of the task." On 10/29/14, R2 opined that the phrase "which can empower Ariel…" was not necessary since she said "the same thing generally in the quote that follows." Instead, she urged S4 to "let the observer come to the conclusion!" This recommendation by R2 was unusual in that reviewers generally urged authors to be explicit in directing readers' attention; however, in this exchange, R2 recommended leaving space for readers to "come to the conclusion." S4 took up this comment later that day, agreeing that it was redundant and stating that she removed the phrase. Indeed, in the following version, the phrase was deleted.

R2 also made an important observation about the fifth event on 11/9/14. Regarding the Ladder activity, S4 had stated, “Just as in the presentation of the ‘Guess My Rule’ Problems, no formal procedure on how to solve the problem is given.” However, R2 noted that it is important to point out that no truth table was provided for the Ladder activity and that Ariel “doesn’t appear to connect this problem with the earlier ones as he is trying to find a rule that works generally.” S4 agreed that this is a “great point” and noted that she implemented the change. Thus, she substituted her observation that no formal procedure was given with the statement, “Note that for this problem these values are not provided in truth table.” She also added that idea to her overall description, noting that the Ladders problem was “modeled with Cuisenaire rods and values are not recorded in a truth table.”

S4 received feedback from both R1 and R2 regarding her sixth event. Both recommended small wording changes which S4 took up and implemented in her description. Thus, following R2’s recommendations, she removed the word “please” from statements where she had written “Please notice…” She also said that “Ariel’s method of deriving his solution… involves… a short-cut calculation (*assuming direct proportional reasoning*)” instead of writing that the calculation was *based on proportional reasoning.* “

R2 recommended cutting out video from the beginning of the seventh event which showed the researcher asking Ariel how many rods would be in a ladder with 100 rungs since the narrative for the event did not mention this exchange but rather began with Ariel’s justification of his solution of 34 rungs for a ladder with 10 rungs. S4 replied on

11/9/14 that she had implemented the change to focus the event solely on Ariel's justification, starting her event 38 seconds later than she had previously.

R2 suggested that S4 clarify her description of the eighth event. Instead of stating that "Ariel has derived a way for calculating the number of steps needed to construct a Ladder *with both an even number and odd number of steps*," she should clarify that he derived a way to calculate "the number of steps needed to construct Ladders with *either an even number or on odd number of steps."* This recommendation was taken up by S4 and implemented in her next version. Additionally, R2 suggested that instead of stating, "Here Ariel's 'rule' for 'Even Numbers' is a procedure," S4 could state, "Here Ariel is describing his procedure for 'Even numbers.'" However, due to the changes implemented based on the comments discussed in the next paragraph, this change was not implemented.

R2 questioned the validity of S4's interpretation of the eighth and ninth events. In the description of the eighth event, S4 had stated, "Here Ariel's "rule" for "Even Numbers" is a procedure. Mathematically, Ariel's procedure is equivalent to the much simpler rule (which is actually embedded in his procedure) of 'multiply the number of steps by three and add two' to obtain the number of total rods." R2 observed:

> This is a great event - and does describe his attempt to reconcile the conflict that comes from his proportional reasoning when compared to counting the rods in his models - But I don't think that your "simpler - multiply by 3 and add 2" is embedded in his thinking at all… I… wonder how best to express his attempt to reason around his belief rather than trying to analyze the situation."

S4 responded on 10/29/14 that "the simpler rule is not in his thinking--but it is in his procedure----I don't know how to describe his reasoning--again, have to think about this and watch him again." However, R2 objected that "I don't see it in his 'procedure' -

seems to me we are assuming it." S4 took up R2's comments in her changes to the event, changing her original sentences to:

> "Ariel offered a composite function depending on whether the number of rungs in the ladder was odd or even" (Maher, Sigley, & Wilkinson, 2013, p. 219). Ariel's rule for "Even Numbers" is long and not elegant; however, mathematically his composite function is equivalent to the much simpler rule of "multiply the number of steps by three and add two" to obtain the number of total rods.

In response to this change, R2 commented, "I think your description works now, let's check with R1."

R2 continued with this line of critique in her comments on the ninth event. However, there she agreed that Ariel noticed that the ladders gained "three more [rods] for every additional step," but noted that he still did not recognize that the formula needed to include the constant of 2 in 3x+2. She asked how S4 could point this out to readers. S4 responded on 10/29/14 that she could quote Ariel and state, "While Ariel does not yet recognize the rule of 'multiply by 3 and add 2' he does notice that for every additional step of the ladder 3 more rods are added. While he finishes writing his 'rule' he says 'for every new thingy you add three.'" R2 agreed that quoting Ariel's words is more accurate than stating that his procedure is equivalent to the formula of 3x+2. Then, very importantly, R2 observed that when S4 stated that Ariel's procedure was "mathematically correct" it is important to note that "his steps are dependent on looking for a particular number of rungs - not yet a general rule." S4 took up this comment on 11/16/14, commenting that she incorporated the suggestion into her description. Thus, instead of stating, "Just like his rule for 'Even Numbers,' these procedures, although complex, are mathematically correct, and the simpler rule of 'multiply the number of steps by three and add two' to obtain the number of total rods would result if one simplified Ariel's 'rule,'" S4 wrote, "Just like his rule for 'Even Numbers,' these steps, although complex and dependent on looking for the number of rungs a particular ladder has, are mathematically correct."

P1 commented again on the tenth event, noting that a particular sentence was very long and should be broken up. R2 suggested prefacing the event by noting that Ariel was taking eighth grade algebra when he was interviewed one year later. Neither of these comments was directly taken up. I

Instead, S4 completely revamped her description of the tenth event in her subsequent version. In that version, she noted that one year passed between Ariel's work on the Ladder problem and his interview with researcher Arias, added that fact to the overall description as well, and described the event in much greater detail.

4.4.3 Second Cycle of Review

On 11/12/14, S4 submitted the revised edition of her VMCAnalytic for further review. R1 and R2 responded by posting comments in the RUanalytic tool.

R2 critiqued the structure of three sentences in the overall description, suggesting a "smoother" sentence structure for one, and suggesting that S4 cut out redundant sections of the other two. S4 took up these comments and implemented the suggested changes.

Both R1 and R2 addressed S4's statement that the IML study was "a 3-Year National Science Foundation-funded longitudinal study conducted by the Robert B. Davis Institute For Learning at Rutgers University." R2 noted that an institute does not conduct a study, but rather researchers do. R1 then suggested verbiage to use to describe the study which S4 incorporated into her overall description.

R1 also objected to S4's use of the word "allow" when S4 stated, "This analytic shows Ariel engaged in problems that allow him to build his own understanding." Instead she suggested using the word "enable," urging S4 to "Think about this. What is it that 'allows?'" Although S4 responded that she removed the sentence completely since it was redundant as R2 had pointed out, she agreed that "when I think of the word 'allow' I think of me letting my children do something."

R2 noted that researcher Davis had used the Guess My Rule and Ladders problems as early as the 1950's. She said they could find the reference to his work with these problems in Schulman's dissertation. After locating the reference, she directed S4 to find the book by Davis entitled "Discovery in Mathematics – A Text for Teachers." S4 responded that she found the book online, but could not find the problems in the book. She requested further help in finding the citation. Although no one responded to her query, she added a few sentences explaining that these problems were originated by Dr. Davis and detailing references to his earlier work.

R2 also directed S4 to remove a clause in the description of the task which noted that one of the values of the truth table was copied incorrectly by the students, since it was "not included in the event or mentioned in the description." S4 took up this suggestion, deleting the phrase and noting that she had implemented the change.

S4 also received feedback from her reviewers about her events. In the first event, R1 made an important observation. S4 had claimed that the Guess My Rule game "invites the seventh-grade students to think about linear functions." However, R1 asserted that this is "actually, not the case. They are given a table of coordinate pairs and asked to find a rule, that turns out to be expressed as a linear function." S4 took up the observation, modifying her description of the event by stating, "This game invites the seventh-grade students to think about given ordered pairs that satisfy unknown rules which can be expressed as linear functions."

R1 also commented on the second event. However, she posted her comment in the comment section for the overall VMCAnalytic and inadvertently referenced the sixth event. R2 observed this typo and pointed S4 to the correct event, saying "R1 really meant this to be for event 2 - you will see what she is referring to." S4 had stated in the second event that "using his own pattern, Ariel includes a number and a valid solution that were not offered by Researcher Powell." R1 said that it was not clear to her that Ariel included a "number and a valid solution" but rather that he found "another ordered pair that satisfies the condition of the problem." S4 took up this comment but although she changed the sentence to "Using his own pattern, Ariel states 'If it was four, you would add a six,' offering an ordered pair that satisfies the problem," she noted that Ariel's statement is technically not an ordered pair. She then requested help in wording the claim. However, her request was not taken up and her description remained as she wrote it.

In the description of the third event, S4 had directed readers to "note that the 'Box' and 'Triangle' have been replaced with the variables x and y." She then questioned readers, "Why do you think this was done?" R2 questioned if her question added anything, though she noted that there is "a correct answer," namely that the students were using a software program for graphing that employed the terms x and y. She suggested that she re-word the question "in a way that encourages the observer to consider when and why for this transition." In response, S4 changed the question to, "What do you think this change can facilitate?" noting that she made the change.

R2 also encouraged S4 to be consistent in referring to the problems as "Problem 1" and "Problem 2" since she had referred to them in the third event as "problem number 1" and "problem number two." S4 took up this comment, saying "Done!" and implementing the change by using the terms "Problem 1" and "Problem 2" respectively instead.

R1 made an important observation about the fourth event. S4 had stated, "While proving his rule Ariel 'notices' a pattern: the constant difference of '2' for y values." R1 objected to her use of the term "proving," saying, "Students are justifying their rules, and NOT proving them." S4 took up this comment, substituted the word "justifying" for the word "proving," and said, "Yes--you are absolutely right--and there is a major difference--this is changed!"

R1 made another related set of important observations regarding the sixth and seventh events. In the sixth event, S4 had noted that Ariel's solution was "based on proportional reasoning" and in the seventh event, S4 commented that Ariel's method "involv[ed] proportional reasoning." However, R1 observed that his reasoning was not only proportional but also direct. Therefore, she recommended that S4 replace the phrase "based on proportional reasoning" with "assuming direct proportional reasoning" and to state that his method involved "direct proportional reasoning." She ended her comment by questioning if S4 knew "why this matters." However, S4 only took up R1's recommendation regarding the sixth event, making the suggested changes, but did not respond or implement the changes suggested in the seventh event. Similarly, she did not take up another comment of R1 regarding the seventh event in which she suggested a change to sentence structure in order make it less awkward. S4 had said that "Ariel now uses Cuisenaire rods to justify his solution of 34 as the number of rods that a ladder with 10 steps has." R1 suggested replacing the phrase "that a ladder with 10 steps has" with "for a ladder with 10 steps." However, this comment was not taken up.

No more changes were implemented in S4's VMCAnalytic and on 6/16/15, R1 recommended the VMCAnalytic for publication.

4.5 S5: Language in Mathematical Development; Part One, Investigating Quadratic Equations

4.5.1 Overview

S5 was another M.Ed. student who created a VMCAnalytic to satisfy a course requirement. Her VMCAnalytic, entitled "Language in Mathematical Development; Part One, Investigating Quadratic Equations" was not published at the time of this writing; however, R1 indicated in an email that when the words "Part One" were removed from the title, it would be ready for publication. This VMCAnalytic contained six events and ran for a little over six minutes (6 minutes, 12 seconds). In the final version of her overall description, S5 clearly stated that the purpose of the VMCAnalytic was to analyze the "use of language in mathematical instruction" and to document students' growing understanding of quadratic equations in an environment that promotes communication. She explained the context of the events, listed the tasks which students worked on, and described the strategies which researcher Robert B. Davis used to encourage communication. First, she explained that he created a safe environment for the children to share their ideas by allowing students to converse among themselves, not labeling their answers as right or wrong, and using questions and humor to guide them. Second, S5 observed that instead of asking students to solve problems, researcher Davis developed the idea of a “secret” which students worked to discover and share with the researcher, only sharing with the group once everyone had a chance to try to discover the secret. In this VMCAnalytic, students only shared their solutions verbally, but S5 stated that her second VMCAnalytic demonstrated the students’ progression from “verbal articulations to written equations.”

In the first event, researcher Davis introduced single variable algebraic equations, using a box to represent the variable. S5 noted that researcher Davis created a safe environment for students to share their solutions by categorizing solutions as either true or false instead of right or wrong. In the second event, Jeff quickly stated a solution to the equation, but after verbalizing his reasoning, he realized that it was incorrect. S5 explained that this event illustrated that when students articulated their ideas, they arrived at more accurate conclusions. In the next event, researcher Davis proposed that the solutions to the problems should be considered “secrets.” S5 proposed that he accomplished two goals with this idea, encouraging students to write down their solutions symbolically and ensuring that students allow their classmates to think of the solution on their own. The fourth event depicted how some students progressed from using a “Guess and Check” method for finding the roots of quadratic equations to using factors to solve for the roots. At this point, students were encouraged to share the secret with the researcher, but not with each other. S5 pointed out that readers should take note of the “positive response” that researcher Davis used with Ankur to encourage him to work on finding a method to solve the problems. In the fifth event, S5 stated that researcher Davis "feels that most students have the secret" of how to solve quadratic equations and focused on three students, including Jeff, who had not yet discovered the method. She noted that as Davis engaged them in a discussion, they got "closer to understanding" and that researcher Davis would continue to engage with them until they would be fully able to express the rule. In the last event, Jeff expressed the rule for finding the roots of a quadratic equation. Students then said they would like to use gym time to work on more problems, and S5 noted that this demonstrated their engagement in the activity.

4.5.2 First Cycle of Review

S5 created the first version of her VMCAnalytic on 12/7/14 and submitted it for review on 12/14/14. The overall description of her first version had the same basic elements and structure as that of her last version, differing mainly in the language used to describe its purpose. The events, too, had only minor changes between the first and last versions.

R2 submitted comments via the RUanalytic commenting tool on 12/18/14. S5 had stated in her overall description, "This two part analytic will look at the use of language in mathematical instruction. In the first segment, we will observe a classroom environment that encourages communication." R2 questioned whether it was a "two-part analytic" or rather a "series of two analytics" of which this was the first which focused on "equations with one variable." In her first event, S5 had included video in which Davis explained what legal and illegal substitutions are but did not include video which showed the students giving examples of legal and illegal values. In a comment regarding the overall VMCAnalytic, R2 suggested adding an event after the first to expand on the idea of "legal" and "illegal" substitutions since this was "important in setting up the environment" to which S5 referred. In her comments on the first event, she again suggested strengthening the narrative by adding "a bit where the students give legal/illegal suggestions."

The second event demonstrated that when Jeff articulated his solution, he recognized that it was false. However, the event video cut off slightly before Jeff finished saying that his solution did not work. Therefore, regarding this event, R2 urged S5 to "cut" the video more precisely so that Jeff's entire response about his proposed solution was included in the event video.

In the fourth event, S5 had written, "We see that most of the students have clearly progressed from 'Guess and Check' to an understanding of the use of factors in solving quadratic equations." R2 observed that the explanation about the "use of factors" was not comprehensive and that she should explain it more thoroughly perhaps by saying that students are "selecting factors of the constant term to try or something like that."

R2 also commented regarding the fifth event. She suggested mentioning the problem statement which was being discussed in the event description.

S5 updated her VMCAnalytic on 1/6/15, taking up many of R2's comments. Instead of writing that the VMCAnalytic was the first of a two part analytic, S5 stated that it "is the first of two," taking up R2's idea that the VMCAnalytics were a series of two instead of two parts of one VMCAnalytic. S5 also more clearly described the type of problems on which students worked in each VMCAnalytic. However, she did not use the language suggested by R2, namely, "equations with one variable;" but rather stated that students worked on finding the "general rule for finding solutions to basic quadratic equations of the form: $ax^2 + bx + c = 0$, for $a = 1$ and b and c both positive integers." S5 also took up R2’s recommendation about the second event to include Jeff’s entire response in the video included in the event. Thus, she added one full minute to the event length, including his entire response as well as other students’ correct responses. However, in this version, the end time of the video was set to 02:1320 instead of 02:13 causing the event to run the full length of the clip until 04:19. This error would be noticed by R2 in the next cycle of review and subsequently be corrected.

S5 did not make any other changes to her VMCAnalytic in this cycle of review. Thus she did not take up many of the comments submitted by R2.

4.5.3 Second Cycle of Review

S5 submitted her VMCAnalytic for review again on 1/6/15. Both R1 and R2 submitted comments regarding her events via the RUanalytic commenting tool.

In the previous cycle of review, R2 had suggested adding video to the first event or creating a new event to show students’ suggestions of legal and illegal substitutions for variables since the first event had ended with researcher Davis explaining the terms legal and illegal substitutions. S5 did not take up R2’s suggestion; however, in this cycle of review, R2 said, “I really like what you have added. Shouldn’t you note the addition in your description for the event?” The version history of the event does not indicate that anything was added to the event, so it is unclear what R2 was referring to. (Perhaps R2 did not remember that the first version had included Davis’s explanation of the terms and thought that it had been added in response to her prior comment.) In any case, S5 did not take up this further suggestion and her description remained unchanged.

As noted, in the previous cycle, the end time of the video of the second event was set to 02:1320 instead of 02:13, causing the event to run the full length of the clip until

04:19. In her comments on 1/7/15, R2 picked up on this mistake and said, “Please check this one - on my computer - the time numbers are weird - and the event runs for 4 minutes to the end of the clip, I think I agree that adding some is great - but you don’t need that much? What did you mean to do?” S5 took up this comment later that day and corrected the end time, setting it to 02:13.

R1 also commented on the second event, noting that Jeff should not be referred to as Jeffrey as S5 had done in the event. R2 concurred, saying that she agrees that Jeff should be consistently referred to as Jeff. S5 took up this comment, saying “It is Jeff! I don’t know what made me put ‘Jeffrey.’” She then updated the title of the event to refer to “Jeff;” however, she did not modify the reference to “Jeffrey” in the description of the event.

In her description of the second event, S5 had stated that “This action [Jeff verbalizing his idea] illustrates the idea that through articulation, the students arrive at more clear and accurate understanding.” R2 opined that it would “be better… not to mention understanding – but rather to note the clarity of articulating the solutions.” Similarly, in the fourth event, S3 had claimed that “…students have clearly progressed… to an understanding of the use of factors in solving quadratic equations.” Again, R2 commented, “It is more objective not to use the word understanding - just that the students are selecting numbers that are factors of the constant term.” However, it does not appear that S5 took up either of these comments as she did not reply to these comments and her descriptions remained unchanged.

In a similar vein, in the fifth event, S5 claimed that “Researcher Davis feels that most students have the secret. He is now focusing on the three students that are still not certain. As he engages them more in the discussion we see that they are getting closer to understanding." R1 said, "We don't know what Researcher Davis FEELS; we only know what he says and does. You might rephrase to say Researcher Davis DECIDES." R2 agreed with R1, saying that she would word it by saying that researcher "Davis has determined (by asking the students!) that most…" of the students "claim to know the secret." Similarly, R1 objected to S5's use of the word "understanding," saying, "UNDERSTANDING what? The sentence is vague. BE SPECIFIC. Do you mean the pattern for determining the rule? Or?" In the sixth event, she noted that S5 wrote that "Jeff can now articulate a rule to find the factors of a quadratic expression." She then asked if that is the "understanding" that she referred to in the fifth event, and if so, she should "say that." In her comments on the fifth event, R2 agreed with R1, saying that she would say that "they recognize the patterns." However, again, there appears to have been no uptake of any of these ideas by S5.

There is no evidence of further activity on this VMCAnalytic. About six months later, on 6/16/15, R1 emailed R2, saying:

> It appears that [S5's] first Analytic, " Language in Mathematical Development : Part One, Investigating Quadratic Equations" might be finished but may need a new title. First of all, remove Part One…. As for a new title, how about something like: Attending to Language as Students Investigate Patterns for Solving Quadratic Equations OR something like that. If you agree, I would like her to make the change and we could recommend for publication?

There is a no record of a response to this email and to date, the VMCAnalytic has not been published.

4.6 S6: Teachers Promoting Mathematical Discourse: Fraction Explorations by Fourth Graders

4.6.1 Overview

S6 started as a part-time student in the Ed.D. program for Mathematics Education in 2010. He began teaching math in 2007 and has taught students in grades 8-12. He first learned of the VMC through his coursework and created his first VMCAnalytics as a course requirement in 2013. He created his VMCAnalytic under study, "Teachers Promoting Mathematical Discourse: Fraction Explorations by Fourth Graders," on 8/21/13 as part of a requirement for his Ph.D. qualifying examination and as a support for his dissertation. He later worked with reviewers to edit the VMCAnalytic in preparation for publication. The final version of the VMCAnalytic had eight events and rans for 15 minutes and 33 seconds. Five of the eight events were over two minutes long and the remaining three were over one minute long.

In the final version of his overall description, S6 explained that research has revealed the importance of collaboration in the mathematics classroom and, thus, teachers need to be prepared to facilitate mathematical discourse in the classroom. He listed Teacher Discourse Moves (TDMs), or moves that teachers can make to facilitate discourse, that were outlined by researchers. These include waiting, inviting student participation, revoicing, asking students to revoice, probing a student's thinking, and creating opportunities to engage with another's reasoning. In his overall description, S6 then described the context of the larger study from which the video of the VMCAnalytic was culled and stated that the video was taken during two sessions of a fraction intervention in Colts Neck, NJ. He then described the problems on which students worked in those sessions, namely to compare the fractions 2/3 and ½ and the fractions ¾ and ½ and to determine which is larger and by how much. S6 then clearly stated that the purpose of the VMCAnalytic was to highlight TDM's that the researchers used and student responses to the researcher's moves. He noted that students were encouraged to justify their answers and researchers asked open-ended questions and encouraged students "to revoice their ideas." He then asserted that the actions of the researchers highlighted by the VMCAnalytic "provide examples of how TDMs can promote higher-level mathematical exploration and thinking in the classroom."

The first event of the final version of the VMCAnalytic depicted Meredith and David explaining their solution to the problem of comparing ½ and 2/3 to researcher Carolyn Maher. S6 noted that the researcher used two techniques, "feigning confusion" to encourage a more detailed explanation of their solution and asking students to prepare an argument to convince other students which invited them to revoice their argument.

In the second event, S6 explained that most of the students had created two models to demonstrate the difference between ½ and 2/3. In the smaller model, the white rod represented 1/6, and in the second, one red rod represented 1/6. In the event, Meredith showed that the difference between ½ and 2/3 is 2/12, but Michael objected to her solution, saying that "you can't use whites to show it." S6 pointed out that the researcher invited "student participation by encouraging students to voice their opinions and openly engage with each other's reasoning."

In the third event, S6 highlighted that the researcher encouraged Meredith to "explain her model and revoice her opinion." He described the "open dialogue structure" that invited students to "explore and discover that 2/12 and 1/6 aren't two answers, but the ‘same thing.’” He added that when the researcher summarized the discussion, she prompted students to “revoice their findings.”

The fourth event highlighted Kimberly’s explanations of her model which she used to compare the fractions ¾ and ½. S6 stressed that researcher Martino used open-ended questions to prompt Kimberly to explain her reasoning. The following event portrayed Brian and Michael as they discussed their solution. S6 pointed out that the researcher waited for them “to make conjectures on their own before refocusing their efforts on the problem” and asked open-ended questions to encourage students to use their own words to explain their reasoning. In the next event, Brian and Michael worked on comparing ¾ and 2/3. In this event, S6 again demonstrated how the researcher invited student participation, namely by encouraging them to explore the problems instead of providing them with answers.

In the seventh event, S6 indicated how the researcher encouraged students to “engage in each other’s reasoning” by asking Alan to figure out why Erik’s solution of ¼ as the difference between ¾ and ½ was incorrect. Instead, Alan realized that his own solution of ½ was wrong. In the last event, S6 depicted how researcher Martino used the techniques of revoicing and waiting to encourage Alan to elaborate on his conjectures regarding the solution of the difference between ¾ and ½. Thus, he concluded independently that despite the fact that he and Erik created different models to show the difference, the solution is always ¼.

4.6.2 First Cycle of Review

S6 created the first version of his VMCAnalytic on 8/21/13. This version was not vastly different than his final version. The main ideas of the overall description were the same between the first and last version, with only minor wording differences. The differences between the first and last versions lay most notably in the descriptions of the events. Whereas the descriptions of the events of the final version clearly explained how the events portrayed various TDMs, the first version merely described the events of the video but did not connect the events to the overall theme. Additionally, the event descriptions of the final version contained a more detailed summary of what took place in the video. Thus, in the first version of the first event, S6 did not explain that researcher Maher invited student participation by encouraging revoicing. The first version of the second event did not describe the video in as much detail as the last version and did not point out that researcher Maher invited students to participate, voice opinions, and engage with each other's reasoning. Similarly, in the first version of the third event, S6 did not describe the video in as much detail as he did in the last version and did not note that the researcher encouraged open dialogue, encouraging students to explore their solutions and revoice their findings. Likewise, in the fourth event, the first version did not explain that the researcher's open-ended prompts encouraged Kimberly to explain her reasoning. Similarly, in the first version of the fifth event, S6 did not point out that the researcher did not interrupt students as they engaged with each other's reasoning. The first version if the sixth event did not explain that the researcher probed the student's thinking and invited his participation by encouraging him to explore the problem. The description of the seventh event was less detailed in the first version than it was in the last and did not state that the researcher created an opportunity for students to engage in each other's reasoning. Similarly, the description of the last event was less detailed in the first version and did not note that the researcher used the techniques of waiting and revoicing to invite the student to elaborate on the connection between the two models of the solution.

R1 commented on S6's VMCAnalytic on 11/18/15 and then again on 1/13/15. R2 submitted comments and suggestions on 1/14/15 and 1/15/15. In response to these comments, S6 updated the VMCAnalytic and resubmitted it for review on 1/18/15.

In her comments of 11/18/15, R1 mainly addressed wording issues. In the overall description, S6 had stated that "…promoting discourse in mathematics has become a larger focal point in the math classroom as of late." In her comments on the overall description, R1 observed that it is unclear what the phrase "as of late" means and suggested using the words "gains increasingly more attention – or something like that." She also recommended indicating the topic and grade level of the students in the title. S6 took up both of these recommendations in his next version, modifying the phrase to say that "…promoting discourse in mathematics has become a larger focal point in the math classroom in recent years." He also updated the title from "Teachers promoting mathematical discourse" to "Teachers promoting mathematical discourse - fractions in grade four," thus taking up R1's recommendation to include both the topic and grade level of the students.

Regarding the fourth and eighth events, R1 noted that S6 should use the title "researcher" rather than "Dr." when referring to the researchers. Additionally, regarding the eighth event, she recommended that S6 avoid the use of language such as "allowing him" since it "connotes to me a different kind of classroom environment." Instead, she suggested using the words "waiting for" to express the same idea. S6 took up these recommendations and replaced the term "Dr." with researcher in all events in which it appeared (although it appeared in more events than those which R1 specifically mentioned). He also replaced the term “allowing” with the term “inviting.”

R1 submitted additional comments on 1/13/15 and R2 commented further on 1/14/15 and 1/15/15. Importantly, R1 commented, “If you could directly connect the behaviors cited in the description to the specific events, it would be even more powerful.” R2 agreed with her comment, saying, “I agree!” S6 took up these comments, noting on 1/18/15, “I have tried to do this now.” S6’s uptake of R1’s and R2’s comments had a great impact on the coherence of the VMCAnalytic. In response to these comments, S6 updated each event to more explicitly explain how the video demonstrated examples of TDMs.

R2 made some recommendations to reword parts of the overall description. S6 had stated, “The following is a selection of video clips from a twenty-five session fraction intervention done in Colts Neck, NJ in 1993. The selection is taken from two separate sessions.” R2 suggested saying that “the events in the following analytic are taken from a selection…The analytic narrative covers two separate classroom sessions…” She also recommended noting which sessions the events were taken from, or at least mentioning that they took place “early in the series.” S6 took up this recommendation, changing the text to, “The following analytic is a selection of events taken from two early sessions of a twenty-five session fraction intervention done in a fourth grade classroom in Colts Neck, NJ in 1993.” On 1/18/15, S6 responded that he had made the changes, but asked if he should state that the sessions took place on Oct. 4th and 6th. However, there is no record of a response to his question, and in the final version, the text remained “from two early sessions of a twenty-five session fraction intervention.”

Additionally, S6 had stated, “As such, there is a greater need for teacher training in the field of promoting mathematical discourse in the classroom.” R2 suggested replacing that text with, “One implication of this Standard is the need to better prepare teachers to promote mathematical discourse in their classrooms.” S6 took up this suggestion, replacing the text with the text suggested by R2 and noting on 1/18/15 that he agreed and had made the change.

Regarding the first event, R2 commented, “Seems to me - rather than C’s confusion - it is her focusing the children on using precise number names - that allows Meredith to provide a strong justification.” She then said, “Seems the important issue is the focus on dark green as ‘1’…The point for me is - not the strategy of ‘feigning confusion’ - rather the ability to allow Meredith to restate her justification using the proper number names - without ‘correcting’ her.” However R1 disagreed, saying that since S6 was focusing on the researcher’s moves, it is appropriate to discuss the researcher feigning confusion, adding that R2’s comment relates “more to student behavior.” She then reiterated that she would not use the word “allow” but would prefer language such as “offering Meredith the opportunity to restate… without correcting her.” R2 responded to R1’s comment by observing that the researcher’s feigned confusion was a good example of a move which encouraged the students to revoice and ultimately justify their solution. But she added that it is important to “identify the teacher move – and connect it to the student action.” She then observed that not only was the feigned confusion important, but that the fact that the researcher was “waiting and listening” was “equally important,” and that it should be noted. S6 took up R2’s recommendation to connect the teacher’s move with the student’s action and her observation that the researcher encouraged the student to revoice their solution, adding that “Researcher Maher’s confusion is a technique that invites student participation and her instructions encourage students to revoice their thoughts.”

Similarly, in her comments on the second event, R2 observed that the event evidenced revoicing by the researcher and “especially by the students in response to her questions…” S6 took up this observation in the next version of this event, and instead of asking readers to “notice how the student Michael is making the argument and stirring the debate,” S6 pointed out that “…Researcher Maher invites student participation by encouraging the students to voice their opinions and openly engage with each other’s reasoning.”

In this event, S6 also took up R1’s recommendation to make sure to specify the problem that students are working on, and substituted his more vague explanation of “Meredith has used white rods in this larger model which has caused confusion in the class” with “Meredith has created this larger model and has used white rods to represent 1/12 in this larger model. She is showing that the difference between 2/3 and 1/2 is 2/12. Michael states that ‘you can’t use whites to show it.’”

In her comments regarding the third event, R2 again highlighted the fact that the event demonstrated examples of both teacher and student revoicing through “argumentation and debate,” and that they clarified their ideas as they listened to each other. She then referenced R1’s VMCAnalytic, noting that “Erik’s statement at the end is what I would call a ‘counter claim’ one that extends and parallels the statement being debated.” Taking up R2’s comment, S6 modified his third event description to point out each instance of revoicing from the video. He stated,

> The researcher encourages Meredith to explain her model and revoice her opinion that 2/12 is the difference. Erik then voices his opinion and concludes that if you combine 2 1/12s you get 1/6. The open dialogue structure encourages students to explore and discover that 2/12 and 1/6 aren't two answers, but the "same thing." Researcher Maher summarizes the discovery with prompts that asks the students to revoice their findings.

R2 also questioned whether the third event could be extended since it cut off after the researcher with the class determined that one red rod = 1/6, two white rods = 2/12, and that 1 red = 2 whites. However, the event did not demonstrate that they extended the argument to prove that 1/6 = 2/12. R2 observed that the event would be stronger if it showed that they returned to the "argument about 1/12ths." S6 took up R2's comment, responding that the following minute of the video "is amazing" since the researcher "revoices the student's understanding by putting it into mathematical language. (adding and multiplication of fractions)." He added, "It's a great example of revoicing. The Herbel-Eisenmann paper describes revoicing as the actual reiteration of a student's argument. They say a great technique is saying something like "Did I get it right?" and Carolyn [the researcher] says something like that." However, S6 expressed concern that adding the extra minute would make the event too long, saying that he was under the impression that three minutes was the maximum recommended length for a single event. He then asked if extending it to be four minutes would make the event too long. However, there is no record of a response to his question, and in the final version, the event remained three minutes long.

In the fourth event, S6 modified the description to connect the event with TDMs as R1 suggested. Thus, he added, "Researcher Martino's open-ended prompts encourage Kimberly to explain her reasoning in her own words."

In the fifth event, S6 also updated his description to more explicitly relate the event to TDMs, again taking up R1's recommendation. Thus, instead of stating that the researcher asked "open-ended questions to have Michael justify his argument," he wrote that the researcher asked "open-ended questions like 'Can you tell me about the model?' to encourage Michael to explain his argument in his own words." Thus, he connected the event more closely to the idea of revoicing. However, he did not use the word "revoicing" to describe the event. Thus, commenting on this new version, R2 noted that this event highlights another example of revoicing since the researcher encouraged "Michael to explain his argument in his own words." However, S6 did not further modify the description of this event to specifically use the word "revoicing."

Again, in the sixth event, S6 took up R1 recommendation to relate the event to TDMs. He added that the researcher is "probing the student's thinking and inviting his participation by having him direct his own exploration." Commenting on this change, R2 noted that the event demonstrated revoicing as the researcher questioned Brian and encouraged Brian to "clarify his thinking as he 'revoices' his ideas." However, again, S6 did not take up R2's suggestion and did not incorporate the idea of revoicing into the description of this event.

In the fourth and seventh events, S6 had used the term "clip" in his description to refer to the video. R2 recommended using the term "event" in each description instead. S6 took up her recommendations, replacing the term "clip" with "event" and noting that he had implemented the changes.

In the seventh event, S6 again more clearly connected the event to his theme of TDMs. Thus, he more clearly described the events of the video, and then added, "Notice that the researcher does not tell Alan that he is wrong; she encourages Erik to provide justification and prompts Alan to find a flaw in Erik's argument. Her technique creates an opportunity for each student to engage in each other's reasoning."

R1 commented regarding the eighth event that S6 should make it clear in each event what problem the students were working on. R2 agreed with R1's comment, saying that since there was a shift from the task of comparing ½ and ¾ to the task of comparing 2/3 and ¾, the new problem should be stated at the beginning of the event description. However, S6 disagreed, saying that he re-watched the video, and that although one student used the term "one-third" in the video, the researcher corrected him. He asserted that, as in the previous event, the students were working on the difference between ½ and ¾ and that the difference between 2/3 and ¾ was not discussed in the event at all. But although he did not take up this recommendation in this event, he modified the second, fourth, and seventh events to more clearly identify the problem on which students were working.

In the eighth event, R2 continued to urge S6 to point out to readers how the TDMs, especially revoicing, were employed by the researchers. S6 had stated that the researcher encouraged the student to "make conjectures" and entitled the event "Encouraging students conjecturing." R2 asked how the idea of "encouraging students conjecturing" fits into his overall theme of TDMs. She suggested that perhaps the researcher encouraged conjecturing by "probing – waiting – and their engaging in reasoning." Taking up these ideas, S6 modified the event description. Thus, he wrote that the researcher "listened" as Alan conjectured, and instead of saying, "By allowing him to talk and explore, Alan is working toward a generalized solution without teacher prompting," S6 wrote, "By revoicing and waiting, she is inviting Alan to talk and elaborate, Alan starts making connections to other models and explaining why the solution is always 1/4 without teacher prompting."

R1 commented on the event's title, "Encouraging students conjecturing." The title of R1's comment was "Event 8 Title." She then wrote "Encouraging Students to Make Conjectures?" apparently as a suggestion of a new title. However, S6 did not take up this comment, although in a later cycle, he updated the title in response to a comment by R2.

On 1/18/15, S6 submitted an updated version of his VMCAnalytic. The changes he implemented in this version took up many of the comments by R1 and R2.

4.6.3 Second Cycle of Review

S6 submitted his changes and received feedback from his reviewers on 3/20/15 regarding many of his events. R2 observed the importance of noting in the first event that the researcher challenged students to "develop equivalent models" and to think of how to convince others of their solution. She asserted that this technique was "at least as important as her 'feigned confusion.'" S6 took up R2's recommendation and added that, in addition to her "confusion," the researcher's "instructions to produce a convincing summary encourages students to revoice their thoughts." He then commented that he "clarified her instructions to help address the convincing others."

R2 urged S6 in the second event "to stick with your TDMs in your titles and the actions that you identify." S6 took up this recommendation, changing the event title from "Encouraging the students to debate" to "Encouraging the students to debate - creating opportunities to engage with another's reasoning." He commented that he made the change and asked if the title was too long. However, he did not receive a response to his question, and in the final version, the title appeared as he had modified it.

R2 made several comments regarding the fourth event. First, she objected to S6's focus on the researcher's open-ended questions. Though she agreed that they were open-ended, she maintained that they were "very intentional," and that the "big idea" of the event was how the researcher "push[ed] for a different 'size' model.'" However, though S6 agreed that the researcher's final question was important, he noted that it was "an extension and not necessarily a TDM" and that the point of the event was to showcase the researcher's "style of not asking specific questions" and inviting the student to "finish" the researcher's statements. R2 responded that she agreed that the researcher initially listened, revoiced, encouraged the student to revoice, and probed her thinking. However, she questioned what type of TDM was employed by the researcher when she encouraged the student to "extend her thinking from models that are the same size - to a proportional one." S6 took up R2's observation, and shortened the event to eliminate the last 10 seconds in which the researcher asked a question to extend the student's thought process. He said,

> I agree that the last 10 seconds of the event started to have Amy do something different that isn't exactly a TDM. It is encouraging her to extend her thought process and not actually promoting discourse. I think the new end time removes that extra element that while is fantastic of Amy, is not necessarily in line with the message of the analytic.

Additionally, in this event, S6 took up R2 recommendation in the second event to include the TDMs in the titles and updated his title from "Open-ended prompts" to "Open-ended prompts that ask students to revoice."

R2 continued to question S6's interpretation of the events as examples of TDMs. In the fifth event, S6 had highlighted that the researcher waited while the students conjectured. R2 asked S6 to "point out what led… to that claim." S6 took up R2's comment by adding to the event description that the researcher "does not interrupt them as they engage with each other's reasoning." He then responded that he liked how the researcher "stopped her line of questioning and just allowed… them to talk and reason…" and that he tried to point out "how she waits" in the description.

As she had done in the previous event, R2 also questioned how S6 "captures" the TDM of the researcher "extending." S6 responded that he agreed that the researcher extended their thinking, but that the "idea of extending solutions into either other models or general solutions could be a great analytic in itself." R2 additionally suggested incorporating the idea that the researcher "create[d] an opportunity for engaging in each other's reasoning" into the title instead of just highlighting the idea of "waiting." S6 took up this suggestion and changed the title from "Waiting and having the students explore" to "Waiting while the students explore and engage in each other's reasoning." He commented, "I like this title better. I agree that they are engaging with each other!"

Regarding the sixth event as well, R2 urged S6 to "analyze [the events] according to [the] TDMs." She asked why the researcher responded with questions, questioning whether it was to "probe his [Brian's] thinking – and then through his revoicing – to clarify his solution as they engaged in his reasoning together." However, although S6 agreed that by probing his thinking, questioning, and directing him to clarify the researcher helped the student clarify his solution, the focus of the event was to highlight the move the researcher made when she asked "What do you think? What are your instincts?" He stressed that he "think[s] this kind of move is so valuable" since it promotes discourse. Although he agreed that from a TDM standpoint the researcher did employ probing and revoicing, his focus was on how the researcher invited the student's participation and encouraged him to take "ownership of his model."

S2 had entitled the seventh event, "Students teaching students." R2 pointed out that the students were "engag[ing] with another's reasoning" more than teaching each other, and that this was another TDM. S6 agreed and updated the title to "Students engaging with another's reasoning."

In the last event, S6 took up R2 recommendation to include a reference to the TDMs in the event titles. He modified the title of the event from "Encouraging students conjecturing" to "Encouraging students conjecturing through waiting and revoicing." He noted the change in a comment, saying that he "changed the title to focus the TDMs."

On 6/15/15, R1 recommended changing the title from "Teachers promoting mathematical discourse - fractions in grade four" to "Teachers Promoting Mathematical Discourse: Fraction Explorations by Fourth Graders." On 6/16/15, S6 updated the title to the one suggested by R1. He then emailed R1 telling her that he had updated the title and that the VMCAnalytic "should be ready now." Later that day, R1 sent an email recommending S6's VMCAnalytic for publication.

4.7 Findings

This study helps us gain an understanding of how participants engaged in intersubjective meaning making and how discussion affected the development of a complex multimedia artifact, namely a VMCAnalytic. This study was guided by the following research questions:

1. How do authors engage with reviewers or peers through the process of multimedia artifact development and revision?
2. How do users take up the ideas of others as reflected by their online or face to face discourse as well as by their modification of multimedia artifacts?
3. How do VMCAnalytics evolve as users take up ideas of others?
4. How do users with different goals, backgrounds, or expertise levels differ in their interaction and uptake processes?

In the following sections, findings from the study will be presented as they relate to these guiding questions.

4.7.1 Authors' Engagement with Reviewers

Subjects varied in the quantity, content, and medium of their discourse with reviewers. S1 received the most feedback from reviewers (n=59), followed by S3 (45), S4 (44), and S6 (27). S5 and S2 received the fewest comments from their reviewers (14 & 8). All the subjects besides S5 took up the majority of the feedback provided by reviewers.

S1 had five cycles of review. Although she emailed her reviewers with Word document attachments containing the text of her VMCAnalytics in her first cycle of review, her reviewers initially gave her feedback via the RUanalytic commenting tool. They only began commenting in the Word documents themselves in later cycles (cycles 3-5). Thus, about 50% of the discourse related to her VMCAnalytic took place in the RUanalytic tool, and about 50% took place via email and Word document attachments. Almost 60% of the feedback on her VMCAnalytic was classified as having a minor impact on it. Thus, although S1 received the most feedback from reviewers, each isolated comment did not have significant impact on the VMCAnalytic; however, taken together, the reviewer's feedback prompted extensive change and much improvement in her VMCAnalytic.

S2 had three cycles of review. She received the least feedback on her VMCAnalytic, but one suggestion had a very big impact on the quality of her VMCAnalytic. This suggestion, which took place during a phone call, urged her to think about framing her VMCAnalytic with a theoretical framework and to tie each of her events to that framework. As a result of this feedback, S2 greatly improved the coherence and theoretical depth of her VMCAnalytic. S2 also received some feedback via email and the RUanalytic commenting tool, but she did not receive feedback via Word document attachments. S2 took up all the feedback she received.

S3 was unusual in that he began working on his VMCAnalytic at the GENI lab while being interviewed by R3. Interestingly, many of the ideas that he revealed in his interview were not explicitly mentioned in his VMCAnalytic until he was prompted by his reviewers to add more detail. S3 had five subsequent cycles of review, and one of those cycles consisted of two parts. Like S1, although he eventually received over half his feedback via Word document attachments, during his first two cycles of review, all feedback was provided via the RUanalytic commenting tool, while during his last three cycles of review, he received all his feedback via email and attached Word documents. In contrast to S1, however, a majority of the suggestions that S3 received had an intermediate impact on the quality of his VMCAnalytic, with an equal but smaller number of comments impacting his VMCAnalytic in a minor and major fashion. Significantly, although Word document edits were not analyzed by this study since they do not offer strong evidence of uptake by authors, it is important to note that in the later cycles of review, reviewers greatly enhanced the clarity of S3's VMCAnalytic by directly editing the text of his descriptions in the provided Word documents. He also received the greatest number of comments from reviewers regarding the coherence of his VMCAnalytic compared with other subjects; 44% of the feedback he received related to the coherence of his VMCAnalytic.

S4 had only two cycles of review and received feedback primarily via the RUanalytic tool; however, she received approximately the same amount of feedback as S3. She received the largest number of comments via the RUanalytic compared to the other subjects. S4 also received the largest number of comments which led to further discussion, with five comments leading to one additional round of comments, and another leading to two additional rounds of comments. These discussions all took place during her first cycle of review.

S5 also had only two cycles of review. She, too, received feedback primarily via the RUanalytic tool, but she received far less feedback than S4. Notably, S5 was the only subject who did not take up most (71%) of the comments which reviewers submitted, and no comments had a major impact on the quality of her VMCAnalytic.

The first version of S6's VMCAnalytic was of the highest quality relative to the other subjects. Like S4 and S5, he had just two cycles of review and received feedback primarily through the RUanalytic tool's commenting feature. He received the largest percentage (60%) of feedback related to the coherence of his VMCAnalytic. These comments were all related to tying his events to his theme of teacher discourse moves and led to a great improvement in the quality of his VMCAnalytic. Additionally, S6 was the only subject who did not receive any feedback related to accuracy. Interestingly, S6 provided the greatest number of explanations in response to comments (in response to 3, or 11%, of comments on his VMCAnalytic) in order to defend why he did not wish to implement the changes suggested by reviewers.

4.7.2 Uptake

Most of the reviewers' comments were fully or partially taken up by users (74%) and users updated their VMCAnalytics in accordance with reviewers' observations. Some comments were further discussed (5%) by the authors and others were explained (3%), i.e., the author clarified why he/she would not be taking up the comment. Some comments were not taken up right away, but were eventually taken up in later cycles (4%). There was no evidence of uptake for 14% of the comments.

Three comments were taken up only partially. R2 observed that the idea of a dust particle in S1's VMCAnalytic came from experience and perhaps constituted a warrant. S1 incorporated the idea that the dust particle came from experience but did not refer to it as a warrant. R2 recommended to S4 she should note that Ariel was taking eighth grade algebra when he was interviewed. S4 added that he was in eighth grade but did not mention that he was taking algebra. Both R1 and R2 recommending using "Jeff" and not "Jeffrey" in S5's VMCAnalytic, but although S5 updated the name in some places, in others it remained as "Jeffrey."

Of those comments that generated further discussion with reviewers, all but one were in reference to S4's VMCAnalytic (one was in reference to S6's VMCAnalytic) and all but one of S4's related to the coherence of the VMCAnalytic (one was in reference to its accuracy). The majority of S4's discussions revolved around sharpening the focus of her VMCAnalytic and greatly enhanced the coherence of her VMCAnalytic. One discussion was related to the accuracy of S4's description of the mathematical basis of Ariel's rule for calculating the number of rods needed to build a ladder with a particular number of rungs. S4 had stated that Ariel's rule for calculating the number of rungs on a ladder with an even number of rungs was "equivalent to the much simpler rule (which is actually embedded in his procedure) of 'multiply the number of steps by three and add two' to obtain the number of total rods." However, this was incorrect, as Ariel's procedure relied upon first determining the number of rods necessary for a ladder with a specific number of rungs. Thus, importantly, R2 noted that Ariel's "steps are dependent on looking for a particular number of rungs - not yet a general rule." After some discussion, S4 modified her statement and wrote, "Just like his rule for 'Even Numbers,' these steps, although complex and dependent on looking for the number of rungs a particular ladder has, are mathematically correct."

Six comments were taken up by users' explanation of why they would not implement the suggested change. S1, S2, and S3 provided three of those explanations, and S6 provided the remaining three. S1 explained that she could not extend the event to include the end of Erik's statement since Alan spoke afterwards, cutting him off. S2 explained that she had already described the role of the girls who presented with Meredith and therefore did not need to repeat the explanation. S3's explanation was provided in response to a comment from R2. S2 had created two events, one in which students worked on finding the surface area of stacked rods and one in which students worked on finding the surface area of stacked rods that were staggered like a staircase. R2 commented on the second of these events, "I never got from the event before that they had successfully found the SA of the stacked rods? so this was a huge leap - The statement of the task needs to be clear." S3 responded, "I am unsure what the leap you are talking about is. I never indicated they were successful in the last task." However, the second of these events was eventually removed from the VMCAnalytic. S6 provided three explanations. In one, he explained that he did not include more video at the end of the event since it was already quite long. In two cases, he explained that he would not focus on the researchers' probing since it was not the focus of his VMCAnalytic. Notably, neither of the novice users provided explanations.

Seven comments were not taken up right away, but were taken up in later cycles of review. Of these, three were directed at S1 and four were directed at S3. Both these subjects had five cycles of review. In the case of the comments directed at S1, two of the comments were repeated in later cycles and then taken up. The third was implemented later on without any further comments. S3 took up four comments from the second and third cycles of review in later cycles. In one, R2 stated that it was "not clear" to her what was "going on" in the event. S2 deleted the event in later cycles of revision. In a second comment, R1 recommended partitioning the third event and describing it in more detail. In later cycles of revision, S2 split the event and vastly improved it. In the third comment, R2 suggested making event five clearer and in the following cycle of revision, S3 shortened the event. Last, R2 suggested removing two events, and in the subsequent cycle of revision, S3 removed those events. In these cases, the suggestions were not repeated although they were taken up at later stages.

There was no evidence of uptake for 28 comments (14%). Of these, three of the comments were coded as unclear. All three were posted in the RUanalytic tool. In two of those cases, in comments directed to S1, it was unclear to this researcher to what the comments were referring. In the third case, in a comment directed to S6, the topic of the comment was “Event 8 Title” and the note section stated “Encouraging Students to Make Conjectures?” The note section then continued with two other recommendations that were taken up. It is likely that the subject did not realize that the reviewer was recommending new wording for the title. In another case, following feedback, S1 removed the entire paragraph which contained the sentence that was the subject of a wording change recommendation, but when the paragraph was later re-instated, the suggestion was not implemented. In three other instances, one in reference to S1’s VMCAnalytic and two regarding S3’s VMCAnalytic, the authors never took up the comment, but the reviewers edited their Word documents in later cycles of review and made the recommended changes.

Some types of comments were not taken up more often than others. For example, 22% of comments related to accuracy and 20% of comments related to clarity were not taken up. In contrast, only 8% of comments related to coherence were not taken up.

Interestingly, missed uptake tended to occur in the earlier cycles of review for subjects with more than three cycles of review. S1 did not take up 23% of all comments in the first three cycles of review, while she only missed taking up only .05% of comments in the last two cycles of review. S3 did not take up 12% of comments in the first three cycles, while he did not miss taking up any comments in the last two cycles of review. In the case of S1, this did not appear to be related to use of the tool versus use of Word documents, since she missed taking up 17% of comments in the tool and 18% of comments in Word. However, in the case of S3, this may have been related to his use of the tool since he missed taking up 15% of comments in the tool, but did not miss taking up any comments in Word.

Of comments submitted in the RUanalytic tool that were not taken up by authors, more comments were missed when posted in the section related to event descriptions (21%) than when they were posted in the section related to the overall description (8%). The number of comments missed in the overall description commenting section is comparable to the number missed in Word documents (9%). When considering comments that were not coded as unclear, this difference between missed uptake in the event commenting section versus the overall commenting section is even greater (20% versus 4% respectively). This difference may be due to the relative difficulty of finding comments posted for individual events to ensure that they have all been addressed.

4.7.2.1 Discourse Initiated by the Subject

Although all review was solicited by the subjects, there were only four cases in which subjects asked for pointed guidance in developing their VMCAnalytics. S2 asked whether or not she should combine the three parts of her VMCAnalytic into one larger VMCAnalytic. Although there was no written record of a response, S2 revealed in an interview that R1 had recommended that she combine them and that she think about a theory with which to frame her analysis. As noted, this conversation proved to be a turning point in the evolution of her VMCAnalytic since it prompted changes which would eventually greatly improve the quality of the three VMCAnalytics. S4 also solicited specific recommendations in titling her events. R2 responded with guidance regarding four of her event titles. These recommendations also had a great impact on the quality of her VMCAnalytic. In the other two cases, S1 and S3 asked for guidance in locating references. S1 asked for guidance on locating papers that may have been published related to the video that her VMCAnalytic drew upon so that she could "reference it in the overall description of [her] analytic." However, ultimately, R1 confirmed that the only related publication was the dissertation that was referenced on the VMC in relation to the video clip from which the VMCAnalytic was drawn. S3 requested guidance finding a reference to support his claim that “Students make much more progress by using the manipulative first and then the symbolic second.” However, there is no record of a response to his question, and the statement was eventually removed from the VMCAnalytic.

4.7.2.2 Discourse Initiated by a Peer

S4 and S5 were both invited to review and comment on each other’s VMCAnalytics. S4 did not comment on S5’s VMCAnalytic, but S5 commented three times regarding S4’s VMCAnalytic (referred to as P1 in that capacity). She noted that it would be important for S4 to state Ariel’s grade level. However, S4 responded that she already noted it in the description, and thus, this comment did not have any impact on the VMCAnalytic. P1 also participated in the discussion with R2 and S4 about including a lengthy quote about the CCSS in the beginning of S4’s overall description. R2 had questioned whether or not the quote was necessary and S4 had said that she thought it was. S5 agreed with R2 that it could be removed without detracting from the VMCAnalytic, but asked if there was “another point in the analytic where it can be pointed out that Ariel is working thoughtfully and not relying on procedures.” R2 responded that S4 could note that Ariel was consistently trying to make sense of the problems. S4 ultimately removed the quote. P1 also made two grammatical suggestions, one which S4 took up and one which she did not. Thus, there was very little impact of peer review on the quality of VMCAnalytics.

4.7.2.3 Discourse Location

Only two subjects used Word documents as a medium of discourse, S1 and S3. Thus, the majority of discourse took place in the RUanalytic tool (69%), with just 23% of comments in Word documents and just 7% of the discourse in the actual bodies of emails. Interestingly, both S1 and S3 were the only two subjects who had more than three cycles of review, and neither received feedback via Word document comments until the third cycle of review. Thus, most of their discourse during the first few cycles of review took place via the RUanalytic commenting tool, with only a few comments submitted via email body. Only in later cycles did they start to receive feedback via Word document comments. This may be due to the fact that it is relatively tedious to comment on minor changes in the tool compared to the relative ease of implementing minor changes in Word by editing and tracking changes. Perhaps when VMCAnalytics needed many improvements, as evidenced by more cycles of review, users decided to engage via Word documents to make the process of editing easier.

This hypothesis is perhaps supported by the fact that although overall there were about as many comments related to clarity as there were to coherence, of the comments in Word documents, more related to coherence (42%) than clarity (20%). On the other hand, of the comments in the RUanalytic commenting tool, more related to clarity (41%) than coherence (32%). Similarly, a larger percentage of the comments in Word documents (56%) had intermediate or major impact than those in the RUanalytic tool (28%). This may be explained by the ease with which reviewers were able to edit Word documents.

Thus, reviewers tended not to comment on clarity or other minor changes in Word, but rather edited the text in-line. When comments were of a more significant nature, reviewers tended to comment in the Word document rather than edit in-line. However, reviewers could not edit in-line in the commenting tool, thus, all observations, whether major or minor, necessitated a comment. In contast, all comments which led to further rounds of discussion took place in the tool. Perhaps the ease with which comments could be posted in the tool supported further discourse, whereas the relative difficulty of creating a comment in a Word document, saving it, and emailing it, hindered such discourse from taking place in that medium.

4.7.3 Evolution of VMCAnalytics

The table below charts the scores of the first and last versions of each the VMCAnalytics created by the six subjects under study.

Initial scores	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
Overall description	2	2	0	1	2	3
Math and theoretical depth	3	0	0	1	1	3
Title	0	0	1	2	2	2.5
Events contribute meaningfully	1	2	1	2	3	2
Clips connect	2	2	1	2	2	3
Claims backed with evidence	2	3	1	1	2	3
Clarity	2	3	1	1	2	3
Coherence	1	2	1	1	2	1

Final scores	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
Overall description	3	3	2	2	2	3
Math and theoretical depth	3	3	3	2	1	3
Title	3	3	3	3	2.5	3
Events contribute meaningfully	3	3	3	3	3	3
Clips connect	3	3	3	3	3	3

Claims backed with evidence	3	3	3	3	2	3
Clarity	3	3	3	2	2	3
Coherence	3	3	3	2	2	3

Table 4.7.3.1. Initial and Final VMCAnalytic Scores

As demonstrated by their scores, the VMCAnalytics of S1, S2, S3, and S6 improved significantly over the course of the review process and scored nearly perfectly in their last revisions. The VMCAnalytics of S4 nor S5 did not achieve perfect scores in their last revisions; however S4's VMCAnalytic demonstrated great improvement from its first version to its last. In contrast, the quality of S5's VMCAnalytic improved only slightly over the course of the review process. Thus, all the VMCAnalytics of all subjects were coded as high quality, besides that of S5 which was coded as low quality. S5 was the single subject who did not take up the majority of the feedback provided by reviewers, thus, it is not surprising that the VMCAnalytic of S5 demonstrated the least improvement from the first version to its last. S1, S2, S3, and S6 were classified as experts while S4 and S5 were classified as novices. Thus, the quality of the final product was poorer for the novices compared with the experts. Although the experts did not necessarily start out with VMCAnalytics of higher quality, their final products were of higher quality. Thus, it seems experts worked towards more perfect end products.

4.7.3.1 Impact of Comments on VMCAnalytic Quality

As noted in the methodology section, comments were coded as relating to one of seven categories: accuracy, citations, clarity, coherence, connections, context, and event length. The majority of comments identified were related to coherence (35%) and clarity (34%), followed by accuracy (17%), event length (6%), context (5%), connections (2%), and citations (2%). However, some comments had a greater tendency to have a bigger impact on the VMCAnalytic quality. Thus, 40% of comments related to context had a major or critical impact on the VMCAnalytic quality and 22% of comments related to coherence had major or critical impact. In contrast, only 8% of comments related to event length, 6% of comments related to accuracy, and just 2% of comments related to clarity had a major or critical impact on VMCAnalytic quality. Since there were many more comments related to coherence than context, the majority of comments with major or critical impact were related to coherence (65%), followed by context (17%), accuracy (9%), clarity (4%), and event length (4%). Thus, of the most common comments, coherence tended to have a more global effect on the quality of the VMCAnalytic, while accuracy and clarity tended to have a more localized effect.

4.7.3.2 Critical Comments

Comments were considered critical if they had a drastic effect on the quality of the VMCAnaltyic. As evidenced below, critical comments tended to be directed at the coherence of the VMCAnalytic, urging authors to explicitly relate the events of their VMCAnalytic to the theoretical elements highlighted by their VMCAnalytics.

Two comments were critical to the development of S1's VMCAnalytic. First, R2 recommended that S1 identify the terms in the descriptions. Previously, S1 had not linked the events to the elements of argumentation described in her overall description. After taking up this comment, S1 modified her VMCAnalytic event descriptions to describe how each event portrayed argumentation. Second, R1 recommended that S1 use students' exact language in quotes. S1 then updated her VMCAnalytic to incorporate quotes of students in 16 of her 17 events.

One comment had a critical impact on S2's VMCAnalytic. This was R1's recommendation to frame her analysis with a theoretical basis. Prior to this comment, S2's VMCAnalytic lacked a theoretical framework. Following this comment, S2 added a theoretical framework and tied each of her events to it. This was critical to enhancing the quality of her VMCAnalytic.

Although there were many comments that had a major impact on the quality of S3's VMCAnalytic, three comments were critical. First, R1 recommended that S3 "follow the process of how students progress from working with rods to building a formula." Previously, S3 had very little reference in the event descriptions to the representations that students employed. Following this comment, S3 added references to the types of representations that were used by students and explained how students progressed from using manipulatives to building a formula. Second, R1 recommended that the overall description "pull together the events." Prior to this comment, S3 had not written an overall description. Following this comment, S3 added an overall description which listed the types of representations highlighted by the VMCAnalytic and noted that the VMCAnalytic would examine how "students use these different representations… to better understand the concepts of surface area and volume." Third, R1 recommended that the text of the VMCAnalytic should be more detailed and should describe or "use actual quotes from students." Following this, S3 updated all the events of his VMCAnalytic, adding more detail and using quotes from students. These changes drastically improved the quality of S3's VMCAnalytic.

Although no single comment directed at S4 had the effect of impacting each event of her VMCAnalytic, one comment from R4 was critical since it prompted S4 to more clearly describe the focus of her VMCAnalytic. Prior to this comment, the purpose of S4's VMCAnalytic was unclear, and thus, it was unclear what story the events were trying to tell. R4 asked, "What is the main purpose of the analytic…?" and urged S4 to "discuss what the events will show." Following this comment and related discussion, S4 updated her VMCAnalytic overall description to clearly state the purpose of her VMCAnalytic. She wrote,

> This analytic provides evidence of student reasoning…. Ariel's engagement in the problems posed by the researchers in this analytic illustrates four Common Core State Standards (CCSS) For Mathematical Practice... This analytic shows Ariel engaged in problems that allow him to build his own understanding.

One comment from R1 had a critical impact on the quality of S6's VMCAnalytic. R1 said, "If you could directly connect the behaviors cited in the Description to the specific event, it would be even more powerful." Prior to this comment, S6 had not explained how each of the events showcased the various TDMs. Following this suggestion, and in conjunction with other more direct suggestions from R2, S6 updated each of his events to describe which TDMs are highlighted by each event. These changes drastically improved the quality of his VMCAnalytic.

4.7.3.3 Discourse and Artifact Modification as Evidence of Learning

As authors discussed and revised their VMCAnalytics based on feedback, they learned more about the mathematical ideas they analyzed in their VMCAnalytics, the theories which they used as a basis of their VMCAnalytics, how the theories are evidenced in practice, as well as the norms of video analysis and VMCAnalytic authorship that have been adopted by a community of researchers who make use of the RUanalytic tool. Thus, comments were coded to reflect these different areas of learning. Most comments were related to how theories are evidenced in practice (45%) and norms of video analysis and VMCAnalytic authorship (38%). Comments related to math (10%) and theory (7%) learning were less common.

Opportunities for authors to learn about mathematical ideas related to their VMCAnalytics occurred in a few ways. Sometimes reviewers commented on the accuracy of the math terminology which users used to describe the video events. For example, R1 recommended that S1 use the phrase "segment of the number line labeled from 0 to 1" instead of "number line labeled from 0 to 1" and the term "infinitely many" instead of an "infinite number." With such comments, authors were encouraged to learn the precise meaning of mathematical terms. Other times reviewers commented on users' accuracy of describing the mathematics in which students were engaged. For example, S4 had stated that Ariel's rule for calculating the number of rods needed to build a ladder with an even number of rungs was "mathematically correct, and the simpler rule of 'multiply the number of steps by three and add two' to obtain the number of total rods would result if one simplified Ariel's 'rule.'" R2 noted that S4 should note that "his steps are dependent on looking for a particular number of rungs - not yet a general rule - but still recursive." This was an important observation since it explained the underlying mathematics of Ariel's rule. S4 took up R2's observation by modifying her description and writing that "these steps, although complex and dependent on looking for the number of rungs a particular ladder has, are mathematically correct." With this change, she removed her claim that Ariel's rule was equivalent to the simplest mathematical formula for calculating the number of rods, noting instead that it was dependent upon finding the "number of rungs a particular ladder has." In this way, S4 was encouraged to learn about the mathematics which underlay Ariel's procedure.

Opportunities for authors to learn about theories which they used as a basis of their VMCAnalytics occurred in a few ways. Sometimes reviewers urged authors to define theoretical terms such as counterclaim, data, imagistic or experiential representations. Other times reviewers commented on the meaning of theoretical terms by discussing examples from the video that embodied those terms. For example, R1 explained that the image of a stamp is an imagistic representation while the action of making the stamp with the white rod is an experiential representation. Defining terms and discussing applications of those definitions provide authors with the opportunity to learn the meaning of theoretical terms more precisely.

Authors also learned about how theories of learning and teaching are evidenced in practice. Such learning opportunities sometimes occurred when reviewers discussed how the video events portrayed theories of learning or teaching. For example, R2 asked S6 how he would classify “questions that extend a student's thinking” as a TDM. S6 responded that when the researcher asked an extension question, it was not an example of a TDM since it encouraged the student “to extend her thought process and [did] not actually promot[e] discourse.” He therefore indicated that he would remove the segment of the video in which the researcher asked the extension question, since “while [it] is fantastic of Amy, [it] is not necessarily in line with the message of the analytic.” In this conversation, R2 and S6 negotiated the meaning of a TDM and recognized that the extension question was not an example of a TDM. S6 therefore removed video footage of the extension question from the VMCAnalytic.

Reviewers also supported authors’ learning about how theories of learning and teaching are evidenced in practice by commenting on the accuracy or clarity of users’ interpretations, claims, and descriptions or urged authors to describe and title events of the video more precisely. For example, S3 had claimed that students lacked "an understanding of the importance of the cube unit." R1 objected and said that the video demonstrated that "not all representations are adequate. [Students] can represent square unit with the stamp; cubic unit with unit cube, but cannot distinguish the two in their symbolic representation and this seems to me to be important…" S3 took up this objection, and clarified that "students did not yet appreciate the importance of those representations of units [two dimensional stamp representing square unit and white cube representing cubic unit] and failed to translate them to the symbolic representation of a formula. So not only are the representations important, but students must also have the ability to move between representations to gain understanding." However, R1 objected to S3's conclusion, saying, "The representations are for different units – square and cubic. So, they are not moving between representations of the same concept. Rather, confusion seems to be between two different ideas – square and cubic units." S6 took up this distinction and modified his description to state that "students must also have the ability to fully understand all aspects of the representation to gain better understanding of the concept." This discussion helped S6 clarify the difficulty that students encountered as they attempted to create a formula for measuring volume.

Authors also learned about the norms of video analysis and VMCAnalytic authorship that have been adopted by a community of researchers who make use of the RUanalytic tool. Reviewers urged authors to cite relevant literature properly, quote students and researchers accurately, describe video clearly and grammatically, title their events appropriately, create a clear focus and purpose for their VMCAnalytics, connect events to each other, situate the events of the VMCAnalyic in the context of the longitudinal study, and cut events precisely so that they each have a specific focus and omit irrelevant details. As a result, users were enculturated into a community of practice that includes teachers, teacher educators and researchers who contribute to a common knowledge base about the teaching and learning of mathematics.

4.7.4 Areas of Difference for Users with Different Backgrounds and Goals

Users with different backgrounds and goals differed in their interactions and uptake processes. S1, S2, S3, and S6 were classified as experts while S4 and S5 were classified as novices. S4 was unique in that she received the largest number of comments which led to further discussion. In those cases, instead of immediately following reviewers' recommendation, S4 followed up with comments of her own to discuss reviewers' observations. Thus, S4 demonstrated the greatest need for follow-up support in order to implement recommended changes. S5 was unique in that she did not take up the majority of reviewers' comments, which may also be indicative of the necessity for additional follow-up support. Additionally, both S4 and S5 produced VMCAnalytics with the lowest final quality.

S6's VMCAnalytic was rated as the highest quality in its first version compared to other users. S6 was unique in that he was the only subject who did not receive any feedback related to accuracy and that he provided the greatest number of explanations in response to comments in order to defend why he did not wish to implement the changes suggested by reviewers. Perhaps the fact that his VMCAnalytic was of higher initial quality and required no improvement related to accuracy are indications that he had put more thought into his first version and was therefore more confident about explaining his rationale to reviewers, as indicated by the number of such responses to reviewer feedback. Interestingly, although each of the expert users provided at least one explanation to reviewers, neither of the novice users provided any explanations.

With the exception of S5, all the subjects were highly motivated to publish their VMCAnalytics. S1, S2, S3, and S6 wanted to publish their VMCAnalytics as support for scholarly research or dissertations. Although S4 created her VMCAnalytic as part of the requirements for two courses, in her questionnaire response she wrote, “I created the VMCAnalytic under study because I wanted to have it published for others to use.” Thus, it seems that she, too, was highly motivated to publish her VMCAnalytic. S5’s VMCAnalytic was created as a course requirement and there is no evidence that she was highly motivated to have it published. Interestingly, S5 is the sole subject who did not take up the majority of reviewers’ feedback and is the only subject whose VCMAnalytic was never actually published. Her VMCAnalytic also demonstrated the least improvement from the first version to its last. Thus, it appears that the goal of perfecting a VMCAnalytic to make it worthy of publication was a strong factor in users’ uptake of reviewers’ feedback.

Subjects differed with regard to the areas of learning they discussed. S1 and S4 received the lion’s share of comments related to math learning (they received 50% and 45% of such comments respectively). S5 only received 5% of those comments, while other subjects did not received any comments about the mathematics of their VMCAnalytic. Perhaps the topic of S1’s VMCAnalytic, argumentation, lent itself to the need for precise explanation of the mathematics in which students were engaged. Of her comments, 17% were related to mathematics. S4 and S5 were both novices and this may explain the large number of such comments they received. Of the comments S4 received, 20% were related to math, while 7% of the comments that S5 received were related to math.

4.7.5 Summary

Authors' engagement with reviewers differed in the quantity and content of their discourse, with the number of comments provided by reviewers ranging from 8 to 59 per subject. Most of the reviewers' comments were fully or partially taken up by users while a minority were not taken up, further discussed, explained, or taken up in later cycles. The VMCAnalytics of all the expert subjects improved significantly over the course of the review process and scored nearly perfectly in their last revisions. In contrast, the VMCAnalytics of the novices did not achieve perfect scores in their last revisions; however one novice's VMCAnalytic demonstrated great improvement from its first version to its last while the others' improved only slightly over the course of the review process. The majority of comments with major or critical impact were related to coherence; thus, coherence tended to have a more global effect on the quality of the VMCAnalytic, while accuracy and clarity tended to have a more localized effect. Most comments were related to how theories are evidenced in practice and the norms of video analysis and VMCAnalytic authorship while comments related to math and theory learning were less common. Novices differed from experts in that they required more follow-up support and produced VMCAnalytics with lower final quality. They did not provide explanations to justify their work. Experts produced VMCAnalytics with higher final quality and did provide explanations to justify their work. The expert with the highest initial quality VMCAnalytic provided the greatest number of explanations and did not receive any feedback related to accuracy. Authors' goal of perfecting a VMCAnalytic to make it worthy of publication was a strong factor in their uptake of reviewers' feedback.

CHAPTER 5 CONCLUSION

5.1 Implications

Findings from this study have implications for the future development of the tool which has potential to become a model others can follow when creating tools for research collaboration. The study identified strengths and weaknesses of the analytic tool as it is used for the review process prior to publication. A primary strength of the tool is the relative ease with which comments could be posted. This strength supported richer discourse, and, indeed, all comments which led to further rounds of discussion or explanations took place in the tool. On the other hand, the relative difficulty of creating a comment in a Word document, saving it, and emailing it, hindered such discourse from taking place in that medium. Thus, the commenting tool proved a stronger support for richer discourse.

However, a weakness of the tool was exposed by the fact that subjects who needed more cycles of review tended to revert to emailing Word document attachments in later cycles of review. Exchanging Word documents enabled reviewers to edit the VMCAnalytics in-line and track their changes. As noted in the findings, reviewers tended not to comment on clarity or other minor changes in Word, but rather edited the text in-line. However, in the tool, reviewers could not edit in-line, and thus, all observations, whether major or minor, necessitated a comment. This commenting was tedious, and therefore may have prompted users to use alternate methods of communication. When the tool was designed, developers of the tool may not have fully understood the review process which VMCAnalytics undergo prior to publication and thus may not have fully planned to support that process. Peer review of VMCAnalytics is central to their publication. However, developers may not have realized how tedious the review process is and therefore built the commenting tool to easily support threaded discussion but did not include a document editing capacity. It may be worthwhile to explore adding a feature to support in-line editing and tracking of changes which would make commenting on minor wording changes less tedious and which would be helpful for the review process.

Another weakness of the tool was exposed by the fact that S3 missed taking up 15% of comments in the tool, but did not miss taking up any comments in Word. As mentioned, of all comments submitted in the RUanalytic tool that were not taken up by authors, close to three times as many comments were missed when they were posted in the section related to event descriptions than when they were posted in the section related to the overall description. This implies that users may have found it difficult to find and keep track of comments posted in the RUanalytic tool, especially in the event commenting sections. It may be helpful to address this by creating a way for users to see all comments related to their VMCAnalytic in one space without drilling down into an individual event. This could be accomplished by including related comments in the document created by the VMCAnalytic export feature or by a screen which displays all comments related to the VMCAnalytic. It may be useful for such a screen to provide a way for users to keep track of issues which need to be addressed, in a to-do list fashion.

Another weakness in the tool lies in the fact that comments cannot be visually connected with specific phrases of descriptions. Several comments that were not taken up were unclear or ambiguous. All such comments were posted in the VMCanalytic tool. The ambiguity was due in part to the fact that it was not clear in reference to what phrase or sentences the comments were posted. Therefore, it is important for reviewers to be very clear about what they are referring to in their comments.

Last, this study found that the last event was deleted, apparently accidentally, from S3's VMCAnalytic just prior to publication. The published version of his VMCAnalytic is thus incorrect. That such a mistake could happen by accident and go undetected may or may not be due to a weakness of the tool. In any case, it is vital for reviewers to review the final version of the VMCAnalytic either in the tool itself or as an exported text document just prior to publication to ensure that all concerns were addressed and that no mistakes were introduced.

5.2 Limitations

Because this study was designed as a qualitative descriptive case study and small groups were used to study the uptake process, the results of this study are not generalizable. Additionally, although this study used multiple forms of data, namely the RUanalytic tool collaboration records, email correspondence, Word document attachments, VMCAnalytic history, interview video data, questionnaire responses, and follow-up interview data, it did not account for all possible collaboration that may have taken place. For example, S1 and S4 noted in their questionnaire responses that they discussed their VMCAnalytic with their reviewers in person and clarified comments that they made which were unclear. Data were not collected regarding such face-to-face communication. Also, although effort was made to obtain all email records from the subjects, and there was no evidence of a gap in the email record, there may possibly have been emails exchanged with reviewers that were not collected. Furthermore, this study did not fully analyze edits made to Word documents by reviewers since there was no strong evidence of uptake by users other than their acceptance of changes. However, these edits do represent the joint modification of artifacts and thus the absence of that analysis constitutes a limitation of this study. The study is also limited by the fact that although in many cases it was clear that users took up reviewers' suggestions by implementing their changes, in some case the link between reviewers' comments and users' changes was weaker. This was especially true in the case of three of the comments directed towards S3 that were of a more general nature and led to changes in later cycles of review. Additionally, results have may have been influenced by the fact that the commenting feature was relatively new and unfamiliar to users and this may have impacted their ability to use it effectively. Last, peers were invited to comment on just two of the VMCAnalytics included in this study, so findings from review of peers are very limited.

5.3 Areas of Further Research

This study focused on the process of interaction and uptake evidenced by discourse and artifact modification which resulted from collaborative work. It would be useful to build upon the results of this study by tracing how various theories of social learning were evidenced by the learning phenomena which took place as authors collaborated with others as they revised their VMCAnalytics. Additionally, users were found to differ in their uptake and interaction processes. It would be of interest to study what role, if any, affect played in users' uptake. Furthermore, the sample size used for this study was small and a qualitative methodology was employed, and hence the findings are limited. It would be useful to conduct a follow-up study with a larger sample size to corroborate the findings of this analysis, perhaps using a quantitative methodology. Such a study could analyze patterns of interaction and the affordances of the tool in a more comprehensive fashion.

Appendix: Questionnaire Questions

1. What graduate degree program are you enrolled in? (Ph.D., Ed.D., M.Ed., Other – please specify)? How long have you been in the program? Are you part time or full time? How many credits have you completed? Which courses have you taken? When do you plan to graduate?
2. What is your profession? (Please select as many as apply: teacher, teacher educator, researcher, other – please specify) How many years of experience do you have for each role? If you selected teacher, what grade levels have you taught and which grade do you currently teach? If you selected teacher or teacher educator, which courses have you taught?
3. How did you first learn about VMC? How did you first learn about VMCAnalytics?
4. How did you learn to make VMCAnalytics? Any training? Describe.
5. Why did you create the VMCAnalytic under study? (I will specify the title here for each participant.) If you created it for a course, which course was it created for?
6. If the VMCAnalytic was not created as a course requirement, what motivated you to create your VMCAnalytic?
7. What was the theme or purpose of your VMCAnalytic?
8. Describe how you used the RUanalytic tool's commenting feature and email during the revision the process?

Did you receive feedback? From whom? Was it helpful? Why/whynot? How has the feedback that you received affected the development of your VMCAnalytic?

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