Showing What They Know:
Multimedia Artifacts to Assess Learner Understanding

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Abstract: Engaging learners in constructing multimedia artifacts provides rich opportunities for them to make their thinking visible. In this research, we demonstrate the use of the VMCAnalytic, a multimedia artifact that builds on an extensive video collection of children's mathematical reasoning. Using reliable rubrics, we coded all VMCAnalytics created in a range of classes. These rubrics focused on the quality of the students' arguments and depth of their reasoning. Analysis showed that the rubric was useful in differentiating among the different groups of students. Moreover, different metrics had different degrees of correlation, suggesting that we were identifying several different dimensions of quality.

Engaging students in technology-rich projects provides opportunities for both learning and making their thinking visible (Collins & Halverson, 2009). Creating multimedia artifacts offers opportunities for learners to engage with substantive content through their designs (Kafa & Ching, 2001). Building on earlier research with a video repository, we provide opportunities for students to engage in generative activity through construction of multimedia artifacts by making use of a new tool, the VMCAnalytic (Agnew, Mills, & Maher, 2010). In prior work, we examined a range of course contexts and tasks in which learners used the VMCAnalytic (Hmelo-Silver et al., 2013). In current research, we extend the range of contexts in which learners' use of the tool to construct multimedia artifacts enables assessment of the complex knowledge required for understanding, teaching, and researching the development of mathematical reasoning in students across several content domains. In particular, we examine how graduate students create arguments using videos of student reasoning by bringing together ideas from mathematics education and the learning sciences with the perceptual grounding of classroom practice to warrant claims about learning. Our research questions for this paper are as follows:

(1) To what extent can we use a cyber-enabled multimedia construction tool to assess how well learners justify their arguments about children's reasoning?
(2) To what extent do students identify relevant concepts in making their claims?
(3) How, if at all, does variation in course context, with differing instructional guidelines for completing a task, relate to qualitative differences in the multimedia artifacts that students produce?

We conjecture that studying these questions will guide the further development of formative and summative assessments. Conducting such investigations is of particular interest to the field of the learning sciences, where practitioners often fill the dual roles of designing activities for student learning and assessing the effects of those activities in order to learn what works to enhance student learning (Schwartz & Hartman, 2007).

The complex knowledge that we expect learners to construct through working with video, text, and practical experiences, entails multiple classes of learning outcomes. Included in their learning space is seeing, saying, and engaging ideas as well as targeting discernment, explanations, and contextualization (Schwartz & Hartman, 2007). Construction of multimedia artifacts with the VMCAnalytic tool supports student assessment by allowing us to identify the strength of arguments posed and the quality of their reasoning about mathematics education and the learning sciences.

Our research investigates the affordances and constraints of using multimedia artifact construction as a means of assessing the knowledge that learners have constructed about the development of mathematical reasoning and what they view as implications for teaching, learning, and/or further research. First we discuss the theories of learning that framed the earlier research yielding the video collection on children's mathematical reasoning and the recent research on teachers studying those videos to attend to students' reasoning. This is fundamental and relevant to the theory of learning through artifact design as a context for the current research. We then describe the resources on the video repository to illustrate what learners have available for constructing their multimedia artifacts, and share some results demonstrating the promise of the videos for learning about students' mathematical reasoning. This serves as a basis for exploring a technology-enhanced assessment for learners to show us what they know.

Theoretical Perspectives

Teachers seeking to promote students' competency to represent, communicate, and justify their ideas in the context of doing mathematics are faced with the challenge of developing their own adaptive expertise as educators (Bransford, Derry, Berliner, Hamerness, & Darling-Hammond, 2005). High quality teaching demands the ability to spontaneously and flexibly identify, critically evaluate, and respond in appropriate ways to instances of children's learning. In mathematics it is particularly important to attend to emergent forms of reasoning as children express justifications using their own language (Hiebert et al., 1997; Yackel & Hanna, 2003). To build such capacity, teachers must know how to solve math problems, but must also come to recognize and understand the reasoning that justifies valid solutions to those problems (Maher, Landis & Palius, 2010). Consistent with the view of active knowledge construction, teachers need opportunities to engage as learners in building knowledge for teaching mathematics. There are several models for mathematics teacher education and professional development that use video as a tool to make instructional practices available for study, interpretation and discussion (e.g., Borko, Jacobs, Eiteljborg, & Pittman, 2008; Zhang, Lundeberg, & Eberhardt, 2011). The VMC video collection offers particularly valuable resources for teachers to build understanding of how students learn mathematics and conditions that promote development of mathematical reasoning. Because teachers typically have learned math in ways that relied heavily on procedural knowledge, facilitation of their learning entails engaging them in problem-solving tasks and justifying their solutions to build a deeper conceptual understanding of the mathematics and learning to attend to ways that students engage in those activities by studying video episodes.

Our goal is to advance teacher learning to the next level by engaging them in the construction of multimedia artifacts for sharing what they have come to understand about the development of mathematical reasoning or about learning more broadly. We define artifacts as "digital representations created by students that communicate their understanding, application, analysis, or evaluation of relevant ideas." (Rodriguez, Frey, Dawson, Liu, & Ritzhaupt, 2012, p. 358). While teachers' prior learning activities involved a video playback tool, their work with VMCAnalytic utilizes a video-editing tool. As with other video editing tools, such as WebDiver (Zahn et al., 2010), the VMCAnalytic enables selection of segments of video that can be annotated and remixed to form multimedia narratives of reflection and analysis for a variety of purposes (Hmelo-Silver et al., 2013). VMCAnalytics are shared, as they become objects of discussion, whether created individually or collaboratively. The process of constructing the analytics allows meaning to be negotiated and potentially refined for greater clarity and coherence.

Using a Video Repository

Support from four National Science Foundation grants for longitudinal and cross-sectional research studies produced over 4500 hours of video and related data showing students doing mathematics from elementary grades throughout high school and beyond. The Video Mosaic Collaborative (VMC, see: www.videomosaic.org) was built as a repository that houses a unique video collection, amassed from a quarter of a century of research (Maher, 2008; Agnew et al., 2010). An important early finding from this research is that young children, in justifying their solutions to problem tasks, provide arguments that take the form of mathematical proof (e.g., analogy, cases, contradiction, induction, upper/lower bound, Maher & Davis, 1995; Maher & Martino, 1996,). From our collection, one can study videos that show the evolution of the development of students' arguments over several years and follow how students' ideas are originally represented, shared, then expanded, and then generalized. The videos give examples of children's early strategies and heuristics and the durability of their early ideas, later expressed in more elegant form. One can follow the elaboration of student reasoning over several years and observe the richness and depth of understanding that has evolved over time as students make connections between and among ideas and express their solutions using formal notation and language to give meaning to the symbols (Maher, Powell, & Uptegrove, 2010). Because the research was conducted in working class, urban and suburban environments and in classrooms as well as informal, after-school settings, the collection is rich, not only from its longitudinal nature (some students are followed throughout schooling and beyond) but also because of the variety of contexts and content strands in which the research was conducted. As part of ongoing work, we continue to populate the VMC with series of short clips and full-length videos of problem-solving sessions from the collection by cataloging them with extensive metadata to enable a variety of search paths for discovering resources.

As videos get ingested to the VMC, they become publicly available resources for use in teaching, teacher education, and research (Hmelo-Silver et al., 2013). They also become available for use in the workspace of the VMCAnalytic tool as Figure 1 shows (Agnew et al., 2010). Following initial piloting and design revisions, we engaged learners in using the VMCAnalytic tool to construct multimedia artifacts for a range of purposes in a variety of graduate course and research contexts. Experiences with the VMCAnalytic tool have been preceded by participation in an instructional intervention during which videos from the collection were studied.

We have engaged in a program of design-based research to use the VMC resources for teacher education studies (Bielaczyc, in press). In particular, for pre and in-service teacher interventions, we have examined the effect of studying videos of student reasoning on teachers' growth in recognizing forms of reasoning used by children in the videos. Interventions were conducted in which study participants were asked to describe the details of children's arguments offered in justifying solutions to a specific problem-solving tasks (Palius & Maher, 2013; (Maher, Palius, Maher, Hmelo-Silver, & Sigley, 2014). In each strand, the task elicited multiple forms of reasoning that participants could recognize.

In the counting strand, a study based on our initial interventions investigated whether teacher study of VMC videos improved their ability to recognize a variety of forms of reasoning expressed by the children in the assessment video (Maher, Palius, Maher, Hmelo-Silver, & Sigley, 2014). Video assessment data were analyzed to measure growth from pre to post assessment for recognition of forms of reasoning. Results indicated that, on average, 60% of the in-service teachers and 36% of the experimental pre-service teachers improved on the post-assessment in recognizing the various forms of children's arguments, compared to the average of 5% improvement for the comparison group of pre-service teachers.

Figure 1. Screenshot of the VMCAnalytic tool

A study conducted in the fractions strand investigated teacher learning in an experimental online course using discourse analysis as well as analysis of their video-based assessment data (Palius, 2013). Teacher-learners in the experimental intervention were more likely to demonstrate growth in their ability to recognize different forms of students' mathematical reasoning compared with comparison groups (Palius & Maher, 2013). Although results from these studies using video-based assessment data are not conclusive, they offer evidence of promise of the VMC videos as resources for learning about students' mathematical reasoning. These findings have led to shifting our focus to the prospects of the VMCAnalytic tool for assessment.

Technology-Enhanced Assessment

Learning technologies are providing new opportunities to teach thinking and reasoning and what students can be expected to do to show their knowledge and skills (Pellegrino & Quellmalz, 2010). These changes allow us to think about what is assessed and new ways to provide evidence of understanding. In particular, technology allows assessing a range of complex performances (Pellegrino, 2013) An important source of evidence for assessment can be found in the artifacts that learners create with technology (de Jong, Wilhelm, & Anjewierden, 2012). In particular, technology provides a high level of expressiveness as learners can create multimedia artifacts. There is also evidence that assessment based on teacher's analysis of video can predict student learning outcomes. For example, Kersting, and colleagues (Kersting, Givvin, Sotelo, & Stigler, 2010) used a video analysis task to assess teacher knowledge. To score the teacher's analyses, they used a rubric that measured Mathematical Content, Student Thinking, Suggestions for Improvement, and Depth of Interpretation on a 3-point scale. They found that suggestions for improvement predicted student learning. Unlike the Kersting et al. study, in our work, the VMCAnalytic is an embedded assessment that is both designed to support learning and to provide an occasion for assessment.

The VMCAnalytic provides opportunity for students to make their thinking visible and provides unique opportunities for assessment because students must bring together conceptual knowledge and the rich videos of learning in action (Derry, Hmelo-Silver, Nagarajan, Chernobilsky, & Beitzel, 2006). As Pellegrino & Quellmalz (2010) note, technology offers opportunities for innovative assessment of complex skills along while allowing scaffolding that promotes learning. Although the VMCAnalytic provides opportunities for eliciting complex performance, we consider this to be part of an instructional system that includes teacher scaffolding and rubrics that make expectations clear for both learners and instructors. The VMCAnalytic thus provides a means for instructors to monitor what students are learning and help scaffold their progress as a formative assessment and can provide evidence of a student's (developing) competence. Although space precludes providing examples of VMCAnalytics here, we refer the reader to examples of published VMCAnalytics: http://bit.ly/1hZcjoR.

Methods

The data analyzed in this paper come from 63 VMCAnalytics that were created over the last two years by participants in 7 courses. The VMCAnalytics were graded on an integer scale from 0 to 3 on two levels; a local individual event level and a global level evaluating the VMCAnalytic as a whole. Each event that contributed to the participants VMCAnalytic was rated on how well the event fit into the overall description. Examples of high scoring events included text in the description that explained how the video they chose lent support to their overall description. Lower scoring events tended to select video but not situate it or made faulty inferences from the video. The scoring rubric is shown in Table 1. Two independent coders with expertise in evaluating and creating VMCAnalytics scored the 63 VMCAnalytics. Inter-rater reliability between the two coders was 88.72%.

Table 1. Scoring rubric

Criteria	0	1	2	3
Overall description of the analytic is very explicit about what it shows	Off topic	On topic, but vague about what analytic will show	Discusses topic explicitly, but is only related peripherally to topic and does not capture its essence	Captures essence
Each event contributes meaningfully to the overall purpose of the analytic	Most events are extraneous or weakly linked to purpose	Most events contribute well, some extraneous and have no connection	Most events contribute well, some are weakly linked	All events contribute strongly to the purpose
Clips connect to each other in a meaningful way	No easily discernible logical sequence	Some events are in sequence, most are not	Most events are connected, some seem unconnected	All events are in logical sequence
Claims are backed with evidence	No claims made are backed by evidence	Some claims backed by evidence but most are not	Most clams backed by evidence, a few are not	All claims made in descriptions backed by video evidence or research literature
Overall clarity of analytic	Descriptions are all hard to understand/ unclear	Some descriptions easy to understand, most are difficult	Most descriptions easy to understand, some difficult, or overall description unclear	Easy to understand the intent of each description as well as the intent of the overall description
Overall coherence	Hard to understand why any of the events were included or how they contribute to purpose	Hard to understand why most of the events are included but some are easy	Easy to understand why most of the events are included but some are hard	Easy to understand why each event included. Overall description describes purpose well.
Mathematical/ Learning Sciences depth	Does not address learning	Superficial use of terminology	Mid-level	Builds on specific learning theory
Fit of Title	Off topic	Vague, cannot predict content based on title	Related to topic peripherally, does not capture its essence	Captures its essence

Because the score a participant received may have been related to the context of the assignment, below we describe the classes on which the data were collected. VMCAnalytics were collected from three semesters of Introduction to Mathematics Education, which is a required class for students to obtain an M.Ed, Ed.D., or Ph.D. degree with a specialization in mathematics education. Several participants were in other degree programs taking the class as an elective. The course used a hybrid format with a mix of in-person meetings and online asynchronous discussions. During in-person sessions, participants worked in groups on problem-solving tasks and shared solutions. For homework, they watched videos on the VMC of students working on the same or similar tasks, read related articles from research literature, and engaged in small-group discussions online

The means by which the VMCAnalytic project in Introduction to Mathematics Education was presented to the students varied for each semester. The participants in the first iteration of the course (n=11) worked initially with a subset of VMC videos about the Guess My Towers task (see videomosaic.org for all video examples). In this task, students must determine and compare various probabilities of different events occurring when building towers four-tall using Unifix cubes while selecting from two colors. The VMC has a series of five videos with fifth graders working on the task over an eighty-minute session. The participants in this iteration of the class worked in pairs creating VMCAnalytics around this task with the constraint that they have a minimum of three events and a maximum of six. The run time of their VMCAnalytic was also to be between four and ten minutes. In the second iteration of the class (n=19), the participants were free to create a VMCAnalytic about any topic. Individuals created their own VMCAnalytic, but groups were formed along common themes. Several participants were interested in constructing VMCAnalytics for professional development around building fraction concepts and met several times throughout the semester for sharing their VMCAnalytics with their group and a course instructor. The group discussions were centered on helping each other improve their individual VMCAnalytics. Similar groups were also formed for teaching algebra concepts and constructing examples with events that demonstrate how to implement the Common Core Standards for Mathematics. In the third iteration during the spring of 2013 (n=11), students were free to use any videos they wanted but were constrained to a ten-minute run time on their VMCAnalytic.

The Critical Thinking and Reasoning course (n=8) is an online, mathematics education elective for graduate students. In this class students watched videos of a group of fourth graders over several months as they explored fraction ideas before they were introduced formally (Palius & Maher, 2013) The participants drew from these videos to construct their VMCAnalytics.

The Early Algebraic Learning course (n=7) is a graduate mathematics education elective. Videos of students engaging in the Guess My Rule task were used extensively in the course. Many participants drew on those and related videos to construct their VMCAnalytics. As in the spring sections of Introduction to Mathematics Education, the participants in this course had a time limit of ten minutes imposed for their VMCAnalytics.

The Design-based Research (DBR) course (n=7 across two semesters) used the VMCAnalytic as part of a brief exercise in video analysis. This course consisted of doctoral students in a range of disciplines and who were focused on research methods rather than mathematics education. We expected these students to focus on more general aspects of learning and collaborative knowledge construction. This group of students was expected to provide a contrast with the other classes. In the 2011 class, limited directions were provided. This was addressed in the subsequent iteration when the assignment was more structured and some students worked in a group. Students were pointed to a limited set of videos rather than the whole repository and were given greater directions as to number of events, length, and the need to make connections to learning theories.

Results

Table 2 contains mean scores and standard deviations for each metric across the different classes. Pairwise differences were computed using the Wilcoxon signed-rank test and found significant differences (all $p < 0.05$) between DBR Fall 2011 and all the other classes except Critical Thinking and Reasoning across overall description, the clips connecting meaningfully, claims are backed, overall clarity and coherence, and event relevance, suggesting that the students with the least preparation and direction had the lowest scores. Significant differences were also found in the relevance of the events between Introduction to Mathematics Education in Spring 2012, where a smaller subset of videos were used, compared with all of the other classes except Introduction to Math Education Fall 2012. This suggests that using the smaller number of videos was beneficial. We conjecture that this is because it reduced the amount of search in which the course participants needed to engage. Moreover, the Introduction to Math Education Fall 2012 class, which was involved in developing the rubrics, did better than all the other classes besides Spring 2012 on events connect meaningfully, claims backed with evidence, and overall clarity/coherence. This suggests that the use of the rubric helped focus student efforts. Although the numbers are too small for a statistical comparison, inspection of the scores for DBR 2012 compared with the 2011 course suggests that the increased structuring of the assignment led to higher quality artifacts being produced.

Table 2. Mean Ratings of VMCAnalytics across classes (standard deviations in parentheses)

Class	n	Overall description	Events connect meaningfully	Claims backed w/ evidence	Overall clarity and coherence	Math depth	Learning Science depth	# of events	Event relevance average
Early Algebraic Learning	7	2.57 (0.53)	2.29 (0.48)	2.14 (0.69)	2.14 (0.38)	1.86 (0.69)	1.71 (0.76)	6.86 (2.03)	2.06 (0.50)
Design Based Research Fall 2011	3	1.00 (0)	1.00 (0)	1.00 (0)	1.99 (0)	1.00 (0)	1.00 (0)	3.00 (3.00)	0.78 (0.69)
Design Based Research Fall 2012	4	2.00 (0.82)	2.00 (0.82)	2.00 (1.15)	1.75 (0.96)	1.75 (0.5)	2.25 (0.50)	7.00 (2.45)	1.94 (0.92)
Reasoning and Critical Thinking	8	2.00 (0.76)	2.06 (0.68)	2.13 (0.64)	2.13 (0.64)	2.00 (0.76)	2.00 (0.53)	9.38 (5.78)	2.27 (0.55)
Introduction to Mathematics Education Spring 2012	11	2.55 (0.82)	2.64 (0.67)	2.46 (0.69)	2.73 (0.61)	2.19 (0.61)	1.64 (0.50)	4.09 (0.70)	2.71 (0.86)
Introduction to Mathematics Education Fall 2012	19	2.52 (0.61)	2.42 (0.61)	2.47 (0.70)	2.42 (0.61)	2.21 (0.71)	1.95 (0.78)	7.26 (2.58)	2.35 (0.53)
Introduction to Mathematics Education Spring 2013	11	2.46 (0.52)	2.00 (0.89)	2.00 (0.89)	1.91 (0.83)	2.37 (0.81)	1.27 (0.65)	8.27 (2.69)	2.12 (0.63)

Table 3. Correlation between measures

	Overall description	Events connect meaningfully	Claims backed w/evidence	Overall clarity /coherence	Math depth	Learning Sciences depth	Number of events	Event relevance average
Overall description	1	0.60	0.72	0.66	0.47	0.38	0.13	0.67
The events connect meaningfully	0.60	1	0.77	0.91	0.56	0.34	-0.09	0.86
Claims are backed with evidence	0.72	0.77	1	0.8	0.48	0.47	0.01	0.75
Overall clarity and coherence	0.66	0.91	0.8	1	0.55	0.33	-0.08	0.87
Mathematical depth	0.47	0.56	0.48	0.55	1	0.092	0.25	0.61
Learning Sciences depth	0.38	0.34	0.47	0.33	0.092	1	-0.05	0.30
Number of events	0.13	-0.09	0.01	-0.08	0.25	-0.05	1	-0.05
Event relevance average	0.67	0.86	0.75	0.87	0.61	0.30	-0.05	1

Correlations were calculated across rating metrics (Table 3). High correlations were found between the clips connecting meaningfully and overall clarity and coherence (r=0.91). This suggests that students who make meaningful connection across events are also more likely to have an overall coherent VMCAnalytic. Similarly, the correlations between clips connecting meaningfully and event relevance (r=0.86), and overall clarity and event relevance (r=0.87) suggests that selecting relevant events is another important factor in the overall clarity of VMCAnalytics. There is a low correlation between the number of events and all of the other metrics suggesting that they are measuring different aspects of learner performance.

Discussion

The VMCAnalytic shows promise of being a useful tool in a system of formative and summative assessment. Constructing multimedia artifacts was an integral component of the instructional design for each of the courses in which they were used, making learner thinking visible and open for discussion and revision. However, equally important is what this research reveals about the kinds of structures and scaffolds that the use of the VMCAnalytic can provide. The rubric provides clear expectations and a roadmap for student use in creating this multimedia artifact as our results from Introduction to Mathematics Education Fall 2012 suggest. Moreover, structuring the task by reducing the amount of video that students need to search also appears to be beneficial as demonstrated by both the Introduction to Mathematics Education Context and Design-Based Research results. For instructors, students' evolving understanding becomes transparent and provides new insights into a student's intellectual journey in thinking critically about children's mathematical thinking and reasoning.

We are now studying the advantages of the opportunities that this assessment provides. As a follow up to this research, a summer research practicum course served as a context for further refinement of the multimedia artifacts made by a subset of participants from the previous semester's Introduction to Mathematics Education and Early Algebraic Reasoning courses. One of the researchers who scored the VMCAnalytics met with graduate students to discuss how their VMCAnalytics were scored using the rubric, and a Senior member of the research team worked with those students to refine their analytics by working on them as a collaborative group focusing on one artifact at a time. An online forum supported the summer practicum as students gave each other feedback based on rubric criteria. These learners shared their work with other members of the practicum community (who worked on different projects) midway and at the end of the term. The next phase of our research will entail detailed analysis of the revision process and how it might have been scaffolded by the rubric as well as current tools and forthcoming technology affordances being designed to support such work.

In our ongoing research, we are collecting additional data to provide process feedback to instructors on how the students are using the VMC as they create VMCAnalytics. Such information offers promise to provide automated analyses to instructors that would support targeted facilitation of student learning. These analyses will draw from log data of student search, iterative refinement of VMCAnalytics, and other forms of learning analytics. In addition, collaboration tools such as threaded discussions and blogs will add opportunities for peer assessment and student reflection.

As we have shown here, the VMCAnalytic is part of a system of learning and assessment. It affords opportunities for learners to make their thinking visible and available for discussion, refinement, assessment, and revision (Collins, 2006). The rubrics can be helpful for guiding students as to what the expectations as well as for researchers in their evaluations. These rubrics help provide constraints on the task that channel the learners in productive ways (Reiser, 2004). Our results demonstrate that providing guidelines for the assignment to create VMCAnalytics are important. As we continue developing and refining the tool as well its use in assessment, we are enthusiastic about the promise of the VMCAnalytic tool.

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