REVEALING SIGNIFICANT LEARNING MOMENTS WITH INTERACTIVE WHITEBOARDS IN MATHEMATICS

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ABSTRACT

The aim of this study was to identify when and how the interactive whiteboard (IWB) functioned as a productive tool that impacted student learning in mathematics. Using video data, field notes, and interview transcripts from 1 school year in two optimal case study classrooms, we were able to examine the unique opportunities afforded by the size of the IWB screen, the manipulation of virtual objects onscreen, and related communication using gestures. We: (i) established criteria for defining “significant learning moments”; (ii) assessed these significant learning moments to determine how the interactive whiteboard was supporting the learning; and (iii) isolated the use of gesture during IWB use to magnify the grain size of our analysis and understanding. The data fell into three types of IWB use: productive (89%), reproductive (2%), and problematic (9%). The study recommends that in order to best support student learning, professional development for teachers should emphasize direct and active *student* use of the IWB to engage students in inquiry of mathematics.

INTRODUCTION

Interactive whiteboards (IWB) have many features that engage students in the classroom, but little is understood about how they actually impact student understanding of mathematics. Our aim in this study was to identify how and why the IWB was a productive tool that impacted student learning in mathematics. As part of this aim, we looked closely at the unique opportunities afforded by the size of the screen, the manipulation of virtual objects onscreen, and related communication using gestures. To do this, we: (i) established criteria for defining “significant learning moments”; (ii) assessed these significant learning moments to determine how the interactive whiteboard was supporting the learning situations; and (iii) isolated the use of gesture during IWB use to magnify the grain size of our analysis and understanding. We define significant learning moments using the IWB as moments that have a clearly positive impact on student understanding because of IWB use. These are, by definition, *productive* instances, in which the use of the IWB is integral to the construction of ideas and conceptual understanding. These significant learning moments are in contrast with *reproductive* instances, in which the actions on the IWB could be reproduced in other ways, and with *problematic* instances, in which technological glitches or use may actually interfere with learning. The study reported here enhances the current literature on the nature and the effects of interactive whiteboard technology use in mathematics classrooms.

Two case studies were conducted in an Ontario, Canada district school board, in mathematics classrooms with teachers of children ages 10-12. The district was encouraging IWB use in classrooms with limited financial supports, causing sporadic distribution of the technology among classrooms and schools. Both teachers were very interested in working with IWBs in mathematics but they had substantially different levels of teaching experience and expertise with the IWB, and worked at different schools. Researchers facilitated collaboration between the two teachers in the form of joint meetings, including bringing in guest experts to share ideas in think tanks. The two teachers received 3 days release time from their classrooms for collaborative activities, and researchers joined these teachers in their classrooms to observe and videotape lessons throughout one academic year. Researchers also conducted interviews to track teacher and student experiences and thinking about IWB use.

LITERATURE REVIEW

A nationwide initiative to install IWBs in each school in the UK began in the early 2000s with an emphasis on technical installation, training, and resource development. In some ways, this has positioned the UK ahead of many other nations in their adoption of IWBs in the classroom. Similar initiatives are occurring internationally, including in Canada, the United States (see Schuck & Kearney,

2007) and stretching to the Eastern Cape of South Africa with comparable technologies such as the eBeam (a portable, digital whiteboard technology; see Slay, Sieborger, & Hodgkinson-Williams, 2008).

Benefits of IWB use identified through early studies included: a) ease of use for whole class teaching including dynamic visual demonstrations (Kennewell & Beauchamp, 2003); b) improved classroom management through IWB engagement; and c) the integrated use of a range of multimedia resources (Ekhami, 2002). Much of the past decade of research on IWBs has focused on student engagement (Glover, Miller, Averis, & Door, 2007; Hodge & Anderson, 2007; Wood & Ashfield, 2008). A key issue noted by researchers was that at the time of IWB introduction in UK schools, teachers were not given sufficient supports to integrate this new technology with their pre-existing pedagogy (Slay et al., 2008). The IWB was therefore used as a static device and limited evolution of teaching practice took place (Holmes, 2009). Further, high costs, the time required for teachers to learn to use the IWB, and continued lack of professional learning have all been identified as challenges to effective IWB use (Beauchamp, 2004; Glover & Miller, 2009).

More recent studies indicate that a greater focus on teacher collaboration and stronger support systems within schools help teachers develop and implement new teaching practices using IWBs (Lewin, Scrimshaw, Somekh, & Haldane, 2009; Warwick & Kershner, 2008). Slay, Sieborger, and Hodgkinson-Williams (2008) suggest that professional learning supports need to be in place before educators use the technology, with a focus on pedagogy that maximizes student learning through the visual and interactive features of the IWB. Teachers who have opportunities to learn to integrate pedagogy with IWB use may, for example, yield more diverse and grounded responses from students, as the IWB enables teachers and students to generate, illustrate, and compare alternative ideas and perspectives immediately during lessons.

To date, research on IWB use has found that: i) digital technologies such as the IWB accelerate learning through accessibility to multiple representations that are unambiguous and clear to students (Goodwin, 2008); ii) this acceleration is highly influenced by teacher competence with IWB technology—competence seen as necessary for teaching students who live in a technologically advanced world (Holmes, 2009); iii) this competence is best nurtured among colleagues within the school, where the sharing of IWB lessons and experiences allow teachers to feel comfortable and supported as their own pedagogy evolves at the IWB (Slay et al., 2008); and, iv) crafting interactive lessons that allow *students* to investigate and manipulate the IWB's tools to showcase their thinking is of greater relevance to student understanding (Bruce, 2012).

Our interest in the use of gestures as an important aspect of learning through IWB use is somewhat unique, and has enabled our analyses to become even more fine-grained. Roth and Lawless (2001) assert that there is little available research “concerning the different roles of gestures and other body movements in

computer-supported and other learning environments” (p. 16). Nevertheless, through observations of students learning with a computer-based physics environment, Roth and Lawless (2001) suggest that tools (such as a computer mouse) that do not encourage the employment of gestures may inhibit and restrict student learning because they lack the sensory and cognitive information inherent to kinaesthetic experiences. Compared to handling physical tools, engaging with virtual tools on an IWB provides students with *different* kinaesthetic experiences. Thus, given that much of the input on an IWB directly employs one’s hands and fingers, the potentially unique role of gestures within the interactive environment of IWB technologies is worth examining.

As gestures are often an inseparable part of communication, the literature differentiates between gestures as expressions of emotion or emphasis and those that are linked to students’ (and teachers’) evolving mathematics understanding. Alibali and Nathan (2007) articulate this distinction by defining *representational gestures* as those where “the hand shape or motion trajectory of the hand or arm represent[s] some object, action, concept or relation” (in Nathan, Eilam, & Kim, 2007, p. 536). Singer and Goldin-Meadow (2005) report that students were able to benefit in learning from teachers’ use of representational gestures when the strategy conveyed through gesture differed from the strategy conveyed through speech. Broaders, Cook, Mitchell, and Goldin-Meadow (2007) found that when students were instructed to gesture, they were able to develop new problem solving strategies. Furthermore, Broaders et al. (2007) found that students encouraged to use gestures were more likely to be cognitively receptive to future mathematics learning compared to those not encouraged to use gestures.

Cook, Mitchell, and Goldin-Meadow (2008) found that students who were instructed to use gestures during learning were able to *retain* the knowledge better than those who did not use gestures. With a sample of 84 3rd- and 4th-grade students, Cook et al. (2008) experimentally manipulated students’ instruction in an equation-balancing lesson by dividing students into three groups: those instructed through and asked to use only verbal responses (*Speech*); those instructed through and asked to reproduce only gestures (*Gesture*); and those taught and instructed to use both the verbal and gesture tools (*Gesture + Speech*). Although Cook et al. (2008) found no differences in student gains between the three groups in an initial post-test, a performance follow-up 4 weeks after the initial instruction revealed a positive difference in retention for students in the *Gesture* and the *Gesture + Speech* conditions: “Children told to gesture during instruction retained 85% of their posttest gains, on average, compared to 33% for children told to speak and not gesture” (Cook et al., 2008, p. 1053).

METHODS

In this qualitative case study research (Yin, 2009), our goal was twofold. First, we were interested in investigating effects of IWB use on student learning

beyond impacts on student engagement. Second, we were interested in deeply analyzing individual teaching/learning instances in order to develop a more fine-grained understanding of how interaction with the IWB enriched or hindered learning. Our sites of learning were two case study mathematics classrooms.

Researchers collected data in the two case study classrooms over 8 months to track teacher and student activity while using the interactive whiteboard in an attempt to expose significant learning moments in mathematics mediated by the IWB. Teacher participants were asked to carry on with their existing problem-based mathematics curriculum, using the IWB as a tool of instruction and learning. Throughout the process, researchers struggled to arrive at a definition of “significant learning moments” related to the study, arriving at the following working definition: moments using the IWB that have a clear impact on student understanding *because of* IWB use. We looked for new understanding facilitated through IWB use.

Participants

Case Study A involved a veteran teacher (Karen) with 12 years teaching experience. Karen had little-to-no background in IWB technology-based practice but was eager to introduce the IWB into her teaching. This classroom (Classroom A) consisted of 24 students (16 boys, 8 girls) ages 11 and 12, all of whom had very limited or no experience in using the IWB. Karen received the support of a technology expert for approximately 6 hours each month to help her get started and troubleshoot.

In contrast, Case B involved a novice teacher (Astrid) with 3 years experience. Having an interactive whiteboard in her classroom for all 3 years of her teaching, Astrid could be considered an advanced user. This classroom (Classroom B) consisted of 29 students (11 boys, 18 girls) ages 10-11; roughly 20 of the 29 students were described as average to advanced users of the IWB because they had been in the same classroom with Astrid the previous year, using the IWB regularly.

Data Sources

Data sources included 20 detailed field notes of observed lessons, transcribed teacher interviews, 18 student interviews, over 12 hours of videotaped math lessons, and 46 student surveys that were distributed and collected at the end of the school year. The survey data served as a form of triangulation for student interviews, ensuring that the interview responses reflected the larger population of students in Classrooms A and B. The survey results are not featured in this particular article. We organized all data into three categories: productive, reproductive, and problematic instances of IWB use.

Commencing on the day of the interactive whiteboard installation in Karen’s classroom, Case Study A began in January 2010 and ended in June 2010. Ten

visits were made to observe lessons with a focus on teacher growth and adaptation to using the IWB. Observed lessons included calculating perimeter and area and adding, subtracting, multiplying, and dividing fractions.

Case Study B began in November 2009 through to June 2010 with 13 classroom visits to observe mathematics lessons. We were able to secure ethics approvals, from the university ethics tri-council, the district school board, the school, parents, and students, to interview six students from Classroom B prior to the study, with midway check-in interviews, and post study interviews in June to track how they felt about using IWBs and how it impacted their learning. Students were also asked to comment on how they felt their teacher's skills and use of the IWB changed or progressed over the year. Mathematics concepts in focus during Case Study B included angles, rotational symmetry, identifying prisms, and order of operations.

At the end of the school year, students in Classrooms A and B were asked to complete a survey that addressed challenges, advantages, and personal development with the IWB; 46 of the 56 surveys distributed were completed and collected. Karen and Astrid were also asked to join researchers for debriefing with video episodes. In these sessions, teacher participants viewed video clips of their lessons throughout the year and provided commentary on themselves and their students. These were later transcribed and coded along with the interviews.

Data Analysis

A five-step process was used to analyze the case study data. First, we reviewed all video data, observation data (in the form of field notes), and interview transcripts to gain a broad understanding of the scope and nature of the data. In the second stage, all observation data and interview data were open-coded (Charmaz, 2003). Open coding included productive (692), problematic (71), and reproductive (15) uses of the IWB.

In stage three, the video data were transcribed and coded to classify broad types of IWB use during mathematics lessons, namely, teacher demonstrations, student practice, student investigation, and consolidation of ideas (Bruce, Ladky, Ross, Mackenzie, & Flynn, 2008).

In stage four, the video data were re-coded to match the codes of interview and fieldnote data as a form of methodological triangulation, arriving at axial codes (themes that were central or pivotal to the study; Charmaz, 2003). Table 1 shows a summary of how all three sources of data were cross-coded and the frequency of each code according to the axial codes.

In the fifth stage, we focused on gesture analysis to better understand the relationship between gesture use, IWB use, and conveying mathematics meaning. For manageability, seven video segments from Classroom B (10 minutes to 1 hour, 10 minutes in length) were selected based on clarity (of the video) and most

Table 1. Stage 4 of Codes and Counts for All Three Data Sources

Code counts	Total count		
	Field notes	Interview transcripts	Video (time)
Illustration and Communication of Thinking			
Using IWB Tools (axial code)	208	272	4:11:47
Use of Tools (UT)	107	165	1:47:59
Justifications of Solutions using Tools (JST)	41	57	1:18:49
Consolidation of Ideas using Tools (CIT)	60	50	1:04:59
Affordances for Pairs Work & Whole Group			
Mathematics Learning (axial code)	128	167	2:01:03
Multiple Solutions at IWB (MSP)	41	62	54:19
Risk-taking at IWB (RTP)	29	26	27:10
Efficiency of IWB (EP)	58	79	39:34
Total Lines/Amount Documented	336	439	6:12:50

active use of the IWB by teachers and students. These seven video segments were then pared down to four learning episodes (from 30 seconds to 10 minutes in length) that were selected for clarity of gestures, instances of the use of gesture to communicate and reason mathematically, and instances where the IWB influenced gesture use. These episodes were then analyzed, through the lens of activity theory (Fitzsimons, 2005) for gesture-mediated learning.

Research Questions

Our key questions in the study and throughout analysis were:

1. Did the IWB support teaching and learning?
2. What do significant learning moments at the IWB look like?
3. How did gesture influence learning in an IWB-mediated environment?

The first research question was general in nature to help us determine whether IWB use was predominantly productive, reproductive, or problematic in relation to student learning. The second question was more specific to revealing how the IWB was being used to enable student learning. The third question allowed us to look even more closely at individual learning moments with an eye to detailed insights into how teachers and students physically manipulated the IWB with related gestures to support their mathematics learning.

FINDINGS

Research Question 1.
Did the IWB support teaching and learning?

Our coding included a simple count of IWB use instances by teachers and students: in our classroom observation data set, we found 71 problematic instances, 15 reproductive instances, and 692 productive instances of IWB use.

Problematic instances involved technology glitches such as poor connections between the IWB and computer, and distractions such as looking for a virtual tool without success.

The teacher invited students to the IWB to manipulate elastics on an online virtual Geoboard. Because the image was built in layers, precise touch with fingers was required. As the first student came to the IWB and manipulated one elastic into a square shape on the virtual Geoboard, the manipulation worked well. When the student went to enlarge the area of the elastic figure, his finger touched the unlocked background layer, prompting the front elastic layer to disappear, rendering it irretrievable. The student at the IWB reset the page and repeated the same steps twice before giving up. The teacher then attempted to use the tool with similar results. This disrupted the focus of students and teacher, as well as lesson flow. (Field note, January 20, 2010)

Reproductive instances involved non-dynamic presentations on the IWB, which could easily have been substituted by a slide presentation or writing on the board for example, or uses where the manipulatives students used at their desks were observed to be equally helpful to support student understanding based on similar student responses and solutions, and students did not gain additional information from IWB use (see Table 2).

As students were gathered at the IWB, Astrid showed slides that illustrated how factoring can be done, along with definitions of prime and composite numbers. Each page on the IWB consisted of definitions and examples. This same introduction could have been accomplished using an overhead or slideshow. (Field note, January 13, 2010)

Table 2. Code Counts of Problematic and Reproductive Instances of IWB Use

Instances observed	Total: 86
Observation of Technology Glitch (Problematic) (OBTG)	26
Observation of IWB as Distraction (Problematic) (OBD)	45
Observation of Non-Dynamic Use (Reproductive) (OBSND)	7
Manipulatives at desk just as illustrative (Reproductive) (OBM)	8

Researchers were surprised with the lack of reproductive instances of IWB use, particularly when reproductive use that supports existing traditional pedagogy is considered a primary type of use in the United Kingdom, according to the extensive 2007 Institute of Education report on *The Interactive Whiteboards, Pedagogy and Pupil Performance Evaluation* (Moss, Jewitt, Lavačić, Armstrong, Cardini, & Castle, 2007).

Whilst overall the impression of the boards was generally favourable within both groups, IWB use is most closely associated with a traditional, front of class pedagogy in which the main gains are from the increased quality of the display. (p. 54)

It is important to note that the participating case study teachers in our study were highly motivated to challenge themselves and their students to maximize IWB use. In this sense, the case study teachers represent an efficacy study (optimal conditions) rather than an effectiveness study (natural conditions).

Productive uses abounded where the teacher used a dynamic IWB feature such as a mathematics content tool, internet link, Flash-based tool, or interactive program, or when teachers provided opportunities for students to do the same (see Table 3).

Using a YouTube video of skateboarders, the teacher screen-captured a skater in mid-flight and imported the image into Notebook software. She then used a virtual protractor on the skateboard picture. She then used the straight line tool to emphasize the base of the angle, using the protractor to measure the angle between the skateboard and ground. This demonstration engaged students completely—most students were focused on the angle measurement. In the debrief with the teacher and students, both identified this as an “aha moment. (Field note, November 17, 2010)

Based on these code counts, we concluded that the IWB had an overall positive influence on teaching and learning, with 89% of all coding involving productive use, 9% of coding involving problematic instances, and 2% of coding involving reproductive use.

Similar to other research studies, a high level of positive student engagement was observed. However, our second and third research questions pushed us to look more specifically at *how* the use of the interactive whiteboard enhanced learning during these significant teaching and learning moments.

Research Question 2.

What do significant learning moments at the IWB look like?

Once researchers identified the significant learning moments (those that were productive) in the data set, researchers were then able to identify some overarching characteristics of the significant learning moments. The three intertwining characteristics identified are: (i) the IWB provided *visual support for communication*, linked to the large display size of the IWB; (ii) the IWB provided *opportunities for*

Table 3. Code Counts of Productive Instances of IWB Use

Instances observed	Total: 692
Significant Teacher Learning Moment (TLM)	170
Teacher sharing learning about mathematics (TLMM)	16
Teacher learning about capabilities of the IWB with students (TIWB)	77
Teacher articulated learning about/with students (TLM)	32
Teacher collaboration that enhanced IWB use (TC)	45
Significant Student Learning Moment (SLM)	283
Student learning about mathematics concepts (SLMM)	103
Student learning about IWB capabilities in and for mathematics (SIWB)	18
Collective classroom community mathematics learning moment (WGLM)	116
Specific pairs learning moment about mathematics concepts (PLM)	40
Individual learning moment about mathematics concepts (ILM)	6
Specific IWB Enhanced Learning (OBS)	239
Observation of dynamic use of the IWB to illustrate and generate mathematical ideas (OBSD)	32
Observation of high student engagement (OBSE)	84
Observation of positive IWB impact on student understanding (OBI)	59
Observation of effective IWB use by students that enabled mathematics learning (OBEP)	64

shared student reasoning, including the use of IWB tools to justify and consolidate student thinking and to illustrate multiple solutions (competing and complimentary); and (iii) the IWB provided *opportunities to increase agency*, including use of the IWB to facilitate collective understanding (through risk taking in pairs and small groups).

(i) *Visual Support for Communication*

Students in the case study classrooms frequently used IWB tools to explore and communicate concepts. An IWB tool is a virtual, interactive, and dynamic object or representation that can be translated, rotated, scaled, and utilized in a variety of

ways to convey thinking. Some IWB software-based tools have automated calculation or movement properties (e.g., SMART protractor tool, Geometer's Sketch Pad, etc.). For example, in the case study classes, the students frequently used the virtual protractor, a replication of the standard circle or half circle protractor that students would use at their desks. The virtual protractor was observed to be simpler to use than a "real" protractor due to the flexible orientation of figures and the measuring tool combined.

The IWB's facility in helping students to visualize key concepts and procedures on a much larger physical scale was noted by students as being helpful to their learning. As one student described it,

Well, I think it really helps visual learners, I'm a pretty high visual learner myself. It helps because you can see, as opposed to being told what to do. You can see what's being done and you can even touch and add to what's being done. It really lets the class see what's going on and work together. (Female student, early interview, November 5, 2009)

Pratt and Davison (2003) call this the "visual affordance" of the IWB. Interviews with students from classroom B also confirm the benefits of being able to display work on such a large visual scale.

(ii) *Shared Student Reasoning*

The IWB also supported students in communicating their mathematics thinking to one another which is, of course, tied strongly to the large shared visual space of the IWB. One student described how she distinguished IWB communication from communication of paper-based problem solving.

We use a lot more of the interactive tools. Before we were basically talking about what we learned, but now we're actually showing it, with the protractors and rulers and stuff. . . . If it's on the whiteboard, you can go up and move it and change it so that you understand, whereas on a piece of paper its just fixed there and it doesn't really explain . . . it just has the work. (Female student, final interview, June 20, 2010)

Classroom observations of lessons suggested this same outcome of greater student interaction at the IWB over the course of the study, where students would consistently request the opportunity to illustrate their thinking for the class on the IWB, as opposed to explaining it from their seats during whole class discussions. Students reported that it was easier to challenge ideas, and easier to convince their peers of alternate reasoning, when they were able to use the IWB to illustrate their thinking (including referring to previously generated pictures, calculations, and diagrams of their problem solving, or showing a webpage to justify an idea). They also reported learning more easily from one another:

The angles were really helpful . . . seeing them in real life when we pulled up the skateboards and a lot of the things that Kate and Cameron [classmates]

have been doing . . . like when we had to figure out the volume of rectangular prisms before and triangular prisms, I didn't get that, and I think it was when Kristine came up and was writing some stuff, it was, like, I really understood with what she was saying, how a triangle is half a rectangle. (Female student, final interview, June 20, 2010)

Not only did the IWB help students convey ideas, but it also supported the consolidation of student understanding. Karen explained that, "the consolidation piece was a huge key because we were able to compare two different groups and have a discussion on what made most sense or what was the most effective strategy" (Karen, Audio/video commentary, June 22, 2010). In many instances, this involved the use of a dual screen feature on the IWB that allowed the teacher to simultaneously project bodies of thinking from different students, and to discuss differences and similarities in the ways a problem was solved. It was observed in field notes and video footage that when the dual-screen was activated, students were prompted to ask more questions and give more detailed explanations of their thinking. By enabling students to compare multiple ways of solving problems with the use of a dual screen, students were able to further solidify their mathematical thinking. As one struggling mathematics student explained, "It [the IWB] showed their work and everyone else could come up and share their work and you could compare the two and it could help you learn multiple ways of seeing something" (Male student, final interview, June 20, 2010).

The data from our study also points to students having greater opportunities to persevere with their mathematical reasoning during problem solving tasks at the IWB. As students were given more opportunities throughout the year to use the IWB during problem solving, the forms and timing of teacher support changed. Interjections by one of the case study teachers while pairs of students were working at the IWB decreased as the year progressed and students were increasingly motivated—and were given increased opportunities—to persevere through complicated problems and roadblocks in their thinking with the aid of IWB tools. At the end of the year, Astrid was asked to comment on video of her interjecting with pairs at the IWB and about the gradual release of control observed over time.

Researcher: So why are you more comfortable letting the students use the IWB independently now?

Astrid: Why am I more comfortable letting them go? Because I know that they are on task, I know that they are answering questions in ways that I know I'm not limiting them. If I'm sitting there, then I think they may feel limited in some way. If I'm sitting there [saying] "Oh, why'd you do *that* or why'd you do *that*? OK tell me about *that*". . . just letting them go and explaining how they did it is way more powerful than watching their every move and step-by-step process. (Astrid, Audio/video commentary, June 22, 2010)

There are two interconnected issues at play here for the teacher, resulting in positive effects on student reasoning and communication. First, the teacher

observed the high level of persistence of students when problem solving using the IWB, so she was comfortable with less monitoring of their on-task behavior. Second, because the IWB allowed students to add “pages” for each stage of their thinking, and to review these in discussion with others, the teacher *enabled increased student autonomy of mathematics reasoning* because there was a solid record of student thinking on the IWB. Simultaneously, Astrid shifted from teacher-directed practice to transferring ownership of learning of mathematics to her students.

(iii) *Effective Small Group Learning and Student Agency*

In many cases, groups at the IWB worked through their problems and came to conclusions more quickly than their peers. In these instances, the IWB accelerated student thinking, providing additional time and opportunity for students to explore solutions to problems because of the flexibility and speed in representing ideas that the IWB affords. This resulted in students developing alternate solutions to the same problem within the allotted timeframe and to finding multiple ways of representing their mathematics thinking:

Student at board has completed design on the IWB, placed it on the grid and checked his rotation in 10 minutes. Students at the desk are still drawing their design (their designs aren't very accurate) and are having trouble rotating their drawing because it is on paper. They have to go through the process of tracing they're drawing onto another piece of paper, cutting it out, and rotating it over their original drawing. This process is twice as long and remained incomplete for most by the end of the lesson. Student at IWB is working on second design and trying to create something more advanced; the student has challenged himself with a design that is symmetrically advanced; because there are 2 more minutes in class and student at IWB has finished his second design, he is now working on a 3rd design to check its symmetry; students at desk are still working on their first. (Field note, November 24, 2009)

Video records revealed that pairs of students at the IWB demonstrated strong math language, were on-task, worked to share the manipulation of the IWB, took risks by investigating multiple solutions using IWB tools, and demonstrated a solid understanding of the concepts being learned during consolidation tasks and discussions.

The notion of student agency is interesting here because the students' work is far more public while working on the IWB. In one classroom, a small group was often asked to work at the IWB. During one observation (November 17, 2009), a pair of boys (one higher achieving student who lacked confidence and one lower achieving student) were discussing a problem they were working on at the IWB. As the weaker student (observed during previous lessons to be typically passive in pairs work) was given the opportunity to investigate using the

IWB, he became noticeably more involved and willing to contribute his ideas to further the mathematical thinking. This pair of students was also observed as remaining focused and on task for longer than when they worked at their desks, suggesting that their sense of accountability and agency for their mathematics work may have been higher while using the IWB. In this instance, the students persevered to a final solution they were both satisfied with, in spite of being vulnerable to whole class scrutiny.

The level of accountability for mathematics thinking was observed to be heightened through use of the IWB. We could conjecture that the large scale of the visual display might have an intimidating effect for tentative students, but this proved not to be the case. In both classes, students consistently wanted to use the IWB, to take risks, and to share their mathematics thinking with their peers, resulting in a sense of heightened agency or legitimacy as developing mathematicians.

Research Question 3.

How did gesture influence learning in an IWB-mediated environment?

To examine IWB use with an even more fine-grained lens, we analyzed the role of gesture in student learning because we were intrigued by the way that the IWB engendered representational gestures at the board. The four significant teaching/learning episodes selected for analysis are summarized in Table 4, including a description of the learning episode, a description of gesture use, and an evaluation of whether gesture and IWB use were or were not well aligned in supporting student learning through complimentary or parallel gestures and IWB use.

The detailed analysis of gesture and its relationship to IWB use is particularly dense. For this article, we feature one predominantly well-aligned use of gesture with the IWB (Episode 2) and one poorly aligned use of gesture with the IWB (Episode 1).

Episode 2: IWB and the Use of Related Gestures as Learning Tools

In an open-ended shape sorting activity, students were asked to work in pairs to produce a Venn diagram that classified a group of three-dimensional figures. One pair of students used the tools in IWB software while performing gestures that aided their reasoning. The pair agreed to produce three groups for their Venn diagram classification: rectangular-based solids, triangle-based solids, and circle-based solids. As they contemplated the placement of a hexagonal prism, they struggled with the lack of a hexagon-based group in their diagram. To resolve the issue, one of the students considered rotating the figure on the IWB. Interestingly, the student first attempted to rotate the figure using a grip with his

Table 4. Summary of Teaching/Learning Moments Studied for Gesture Use

Episode	Description of episode	Description of gesture use	Gesture use aligned with IWB use?
1	The teacher has displayed 3D figures on the IWB. Students are asked to classify the figures with justification in a whole class discussion	Gesture as representation of a shape and its properties	No
2	A pair of students are sorting 3D objects at the IWB, justifying their decisions with the support of diagrams they created and a magnifying glass effect	IWB and the use of related gestures (such as rotation) employed together as learning tools	Yes
3	Two students are comparing quantities and magnitude in problem solving; IWB is a recording tool for this thinking.	Use of gesture to relate relationships between abstract objects	No
4	The whole class is focused on work at the IWB which involves representing and measuring angles within figures	Multiple conceptual representations through gesture and the IWB	Yes

index and thumb—as one would attempt when rotating a physical object. He then correctly employed the rotate feature (a circular motion with one finger) of the IWB software to re-position one of the rectangular sides as the base of the hexagonal prism. Following this rotation, the students classified the shape as a rectangular-based solid, and sorted it accordingly.

When prompted by their teacher to explain their classifications, one student extensively gestured to communicate and justify the decisions they made. In justifying the placement of a sphere in its own category, the student claimed that “if you put it on a desk, it will roll, [and] so it has no base.” She showed this using a gesture for a flat surface and a gesture for the arched shape of the face of a sphere. For a flat surface, she held out her hand, palm facing down, and moved it back and forth parallel to the desk in front of her. For a spherical shape, she repeatedly traced a “U” shape with her finger in the air to represent the arc shape of a sphere. Finally, in justifying the placement of a triangular prism as being both

rectangular-based and triangle-based, the student referred to their previous use of the rotate tool on the IWB, and used a “flip” gesture to justify that it can be classified under both categories: with her hand open and palm facing downwards, she “flipped” her hand to orient her palm upwards.

In representing the arc shape of the surface of a sphere, gesture was used in this episode to represent the shape of a figure. In addition, in representing a flat surface, gesture was used to define an environment in which the student could reason about relationships. Gesture was also used to represent changes in spatial orientation, where students represented “flipping” a shape on its side through rotation.

Notably, the IWB functioned as an aid for learning as the students worked through the classification activity in this episode. It is important to note that the standard naming of a prism is defined by its two congruent and opposite faces, with rectangles as the remaining and joining faces. Students were able to debate and question this definition through the visual representation of the figure on the IWB. Through the features of its associated software—most notably, the rotate tool—the IWB enabled the pair to reconsider their classification of the hexagonal prism through rotation. In allowing the students to transform the hexagonal prism, the use of the IWB revealed the students’ thinking in the given task. This episode also links gesture to the students’ cognitive processing; in referring to the image of a sphere on the IWB, one of the students described its shape initially through gesture alone. When communicating the arc shape of a sphere to her teacher, the student employed a gesture for arc before using the word “arc” itself. Consequently, it appears that the student used her gesture for the arc shape to structure her thinking and recall terminology, and not to simply communicate her reasoning.

As an example of poorly aligned gesture and IWB use in the same content-specific area of three-dimensional geometry, we can consider Episode 1.

Episode 1: Gesture as Representation of a Shape and its Properties

In this episode, the teacher presented her students with images on the IWB of a dozen three-dimensional figures and their corresponding names given out of order. She challenged her class to match each figure with its correct descriptive name. As students volunteered to match the figures, a classroom discussion regarding the classification and recognition of three-dimensional solids began. Justifying his choice of placement of one figure, one student claimed that a pyramid has more height than a prism, and a prism has more width (or length) than a pyramid. As a gesture for width, the student held out his hands (palms facing), and slowly moved his hands apart from each other. However, when asked for clarification by his teacher, the student abandoned this gesture and restated his explanation only using words.

Disagreeing with the claim that a pyramid is differentiated from a prism by having greater height, another student suggested that the “sides of a pyramid connect to each other” as he referred to the images presented on the IWB. As he justified his thinking, he also gestured the shape of the pyramid by moving his hands upwards (palms facing, and thumbs up), slowly toward each other and having them eventually meet. Interestingly, to differentiate and represent the shape of a prism, he used the same gesture that he connected to a pyramid: he moved his hands upwards again and, bringing them together, he verbally noted that sides of a prism do *not* come together. The gesture and justification were not aligned.

This episode also featured an interesting exchange between the two students as part of the whole-class discussion. While each student waited for their opportunity to speak, their placement in the room—oriented to be facing the IWB—did not facilitate their communication to one another through gesture. Although it appears that he was attentive, the student who made a mistake regarding the distinction between prisms and pyramids was not watching the gesture presented to him as a response. Although it later appeared that his confusion regarding width was clarified, the cognitive information carried in the gestures used was missed. Although the teacher continued the discussion to clarify the distinction further, she did not make use of the gesture offered by her student. The attention of this student—together with the rest of the class—appeared to be fixed on the teacher and the IWB throughout the discussion. Could the visual appeal of the IWB have drawn students’ attention away from viewing each other’s actions in the classroom? While the data available here cannot answer this question, it raises the significant issue of evolving classroom dynamics in an IWB environment, and the location of students in relation to the IWB during important mathematics discussions.

The two episodes presented here demonstrated that the use of IWB technology—specifically in relation to the use of gesture—can vary greatly between different sets of circumstances. In the second episode, the IWB was used as an active learning tool, where the features of the IWB software were used to extend and enrich the students’ work. Furthermore, the use of gesture and the IWB were complementary in the second episode, where the gestures used were consistent with visuals and actions in the IWB software, and vice versa. However, in the first episode, the focus drawn by the IWB may have actually hindered possible communication through the use of gesture.

While these episodes have focused almost exclusively on the use of gestures by students to demonstrate well-aligned student interaction with the IWB, the other two episodes that are not presented here focused on the teacher’s use (Classroom B) of gesture in the IWB-mediated environment. In her exchanges with students, the teacher was observed to use gestures to relate relationships between abstract objects (such as a comparison of speeds) as well as relating multiple conceptual representations of an angle through the use of gesture and the

IWB. These episodes also provided insight into the modeling of gestures between teachers and students; video footage did not show gestures being explicitly taught to students, but several instances suggested that students and their teacher were using similar gestures (for communicating about graphs, for example) when reasoning with each other. This suggests a shared and evolving scope of gestures. Nevertheless, in the focused capacity of the four short episodes in this analysis, assertions regarding the production and reproduction of a gesture are significant to our study only insofar as their ability to inform our understanding of the use of the gestures and the IWB in shaping student learning.

DISCUSSION

There is a common thread in the research literature indicating that IWB use has the potential to reinforce lesson participation and engagement within classrooms (Glover et al., 2007; Hodge & Anderson, 2007; Wood & Ashfield, 2008), and this was observed in our study as well. But what has remained under-represented is analysis of explicit student learning moments to determine *how* the IWB is being used to support student learning. In this study, there are several interconnected key findings.

First, the IWB facilitated positive learning moments for students due to facilitated shared experience: students had the ability to view multiple solutions and solution strategies on a large screen (for collective viewing and discussion) with the support of software tools that illustrate mathematical thinking dynamically. This supports the “visual affordance” findings of Pratt and Davison (2003). Student interview data supported this strongly as in the example where the student explained how, as a visual learner, the IWB illustrated ideas during whole group discussions that helped her understand “what’s going on.” In this way, the IWB operated as a tool to support co-construction of mathematics ideas, which simultaneously supported the creation of a collaborative learning environment.

Second, when students worked at the IWB, they took greater risks in their mathematics thinking and were more persistent in solving problems than the non-IWB pairs and groups. This was evidenced by example of the two male students of different ability levels who worked together at the IWB to further their mathematics understanding while problem solving. The efficiency of the IWB also allowed students to persist in exploring multiple solutions to problems, as observed by researchers in the rotational symmetry task. This suggests that having students working at the IWB is a key pedagogical consideration in mathematics.

Third, we learned that IWB-mediated learning also supports the use of meaningful gesture: teachers and students took advantage of the IWB as a potential facilitator of gestures to communicate and reason mathematically. For example, one female student used “representational gestures” (Alibali & Nathan, 2007)

to describe the characteristic of three-dimensional solids to roll and slide that were aligned with, but also amplified, her displayed diagrammatic explanation on the IWB. This is important because gestures were used beyond signifying emphasis to also support mathematics learning.

It is also important to consider the role the teacher plays in mediating learning through the use of the IWB. The teachers in the study were both capable teachers who emphasized student-directed learning and student manipulation of both hands-on manipulatives and virtual IWB manipulatives as integral tools for mathematics thinking and communication: this should not be underestimated. The degree of commitment of the teachers to high quality mathematics instruction and learning opportunities for students were essential ingredients to high quality IWB use. Astrid, for example, referred to the “power” of letting students use the IWB to justify their mathematics thinking with little intervention (knowing that the student thinking was recorded on the IWB for later discussion) rather than “limiting” their thinking by acting as a “barrier” to the flow of student reasoning. Nonetheless, not all documented uses of the IWB enhanced student learning; challenges were observed when there were technology glitches and distractions away from seeing useful gestures in the classroom. During whole class discussions, it seems particularly important to carefully consider the integrated nature of non-technology- and technology-facilitated learning opportunities in relation to the physical organization of students and space in the classroom.

CONTRIBUTIONS

Although the benefit of IWB technology as a tool for student engagement is well documented in the literature, our study was concerned with documenting and analyzing the specific uses, gains, and challenges of IWB-mediated mathematics learning through a detailed case study approach. The conclusions of this study augment the literature in this developing area with a relatively comprehensive record of IWB use in two mathematics classrooms. The study indicates that IWBs can have a predominantly positive impact on student learning and student communication of mathematics reasoning. The large majority of learning moments analyzed point squarely to the IWB as a tool that enhances learning opportunities for students.

A major consideration of the gesture analysis in this study was whether the use of gesture in an IWB-mediated environment influenced students’ learning of mathematics. Throughout the significant IWB-related learning moments, students employed gestures to communicate and further their mathematical reasoning in several ways, illustrating that, in an IWB-mediated learning environment, student and teacher gestures in reference to the IWB can form another effective means of interacting with the technology and with the ideas represented through it. These preliminary findings also signal the need

for future research to determine the circumstances that facilitate or hinder the complementary roles of IWB and gesture use. For example, location of the IWB and gaze of students could be analyzed in greater detail across wider samples of students.

In terms of practical contributions, the most fruitful learning moments that were observed in this study could help to inform teacher education and professional development in best practices of IWB use. The overwhelming productive instances of IWB use from this study can be developed into digital examples and video episodes that depict productive instances of IWB use by students and teachers (see digital research papers at www.tmerc.ca). By developing an understanding of the ways that gestures can align with visual representations to form another plane in which students can interact with the IWB, teachers can take advantage of the additional opportunities that exist in the “space” between the students, their communication of mathematics ideas, and the IWB. It is our recommendation that in order to best support student learning, professional development for teachers should emphasize the facilitation of direct and active *student* use of the IWB to prompt and engage students in rich discussions and inquiry into mathematical concepts and skills.

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