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A Geography of Connections: Networks of Humans and Materials in Mathematics Classrooms Using Handheld Technology

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Key words: mathematics education; technology; actor-network theory; materiality; learning; interviews; video-recorded observation; interaction analysis; activity theory

Abstract: This article examines the role of materials in education by investigating the inclusion of a handheld digital technology in mathematics classrooms. By drawing on activity theory to conceptualize learning with technology and Actor-Network theory to understand the relationships between materials and humans, the use of educational technology in two secondary school mathematics classrooms is investigated. Drawing on interviews and video-recorded classroom observation, this investigation maps the patterns of relations among humans and materials as classroom socio-technical networks adapt to the inclusion of a handheld digital technology. The results present a variety of ways that the human and material actors in classroom socio-technical networks operate as an interconnected whole rather than as a set of individual interactions.

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1. Introduction

In the field of educational research, the dominant discourse is squarely focused on the practices of humans such as teachers and students (SØRENSON, 2007). This makes a great deal of sense since education is primarily concerned with human learning. In some cases, however, this focus on human practices may mask the roles that materials play and furthermore limit the richness of understanding concerning learning situations (SHAFFER & CLINTON, 2006). In mathematics education, for example, some researchers have gone as far as to suggest that the intrinsic characteristics of educational technologies cease to mediate learning and become increasingly transparent as learners' incorporate them in their mathematical activities (MEIRA, 1998). Such approaches privilege the role of humans to the point of obscuring important aspects of the meditational role that materials have in mathematics learning and any intrinsic educational value they might have (SHAFFER & CLINTON, 2005, 2006). [1]

In this paper, I focus on the role of materials in education by investigating the inclusion of a handheld digital technology in mathematics classrooms. As a particular technological case, I examine the development and use of the TI-Nspire™[1] graphing calculator from *Texas Instruments* (see Figure 1).

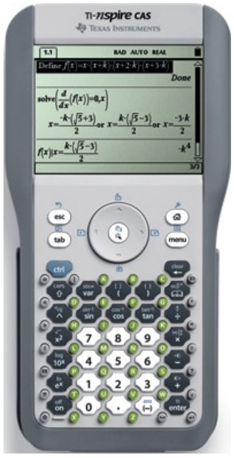

Figure 1: TI-Nspire CAS [2]

Part of the latest generation of graphing calculators to be created specifically for educational use, devices like TI-Nspire have closed the gap between what might be considered a calculator and what might be considered a computer (DRIJVERS & WEIGAND, 2010; KAPUT & SCHORR, 2008). These new technologies use advances in mobile computer processors and displays to offer a range of software applications such as spreadsheet tools, dynamic geometry software and computer algebra systems (CAS) on relatively inexpensive handheld devices (DRIJVERS & WEIGAND, 2010). [3]

To investigate the role of TI-Nspire in mathematics classrooms, I draw on educational research related to the use of educational technology in mathematics learning but I also draw on the field of Science and Technology Studies and in particular Actor-Network theory (CALLON, 1986; LAW, 2002; LAW & MOL, 2001; LATOUR, 2007). Specifically, I use the theoretical tools of Actor-Network theory (ANT) to understand the relationship between humans and materials without overtly obscuring the role that materials play and without discounting their potential intrinsic educational value. Taking the ANT concept that the social is comprised of networks of both humans and non-humans, I map the formation of socio-technical networks in two mathematics classrooms where TI-Nspire from *Texas Instruments* is used. [4]

2. Understanding the Role of Materials in Mathematics Classrooms

Within the mathematics education research community, several researchers looking specifically at educational technology such as TI-Nspire have suggested approaches to understanding the relationship between technology, teachers and students that avoid masking its potential role (BORBA & VILLARREAL, 2006;

1 TI-Nspire™ is a registered trademark of *Texas Instruments Inc*. To avoid repetition the trademark symbol is omitted for the remainder of this document.

HEGEDUS & MORENO-ARMELLA, 2010; SHAFFER & CLINTON 2006; TROUCHE & DRIJVERS, 2010; VERILLON & RABARDEL, 1995). One particularly prominent view is known as the instrumental approach (LAGRANGE, 1999; TROUCHE & DRIJVERS, 2010; VERILLON & RABARDEL, 1995). From this perspective, learner and technology are considered to have a reciprocal relationship and the process by which a technology becomes useful is conceptualized as a movement from tool to instrument as the learner develops schemata associated with the mathematical task that he/she uses the technology to complete. Research drawing on the instrumental approach focuses on the ways in which teachers organize the technologies available to them in the classroom for pedagogical purposes and the ways technologies become meaningful in the context of mathematical activity (DRIJVERS, DOORMAN, BOON, REED & GRAVEMEIJER, 2010; TROUCHE, 2004). While the instrumental approach foregrounds the important relationship between learner and technology, it reduces the role of the technology to that of a mere object waiting to be made an instrument by learners. This understanding moves away from the view that the intrinsic characteristics of a technology become transparent as it is made useful in the context of human practice but still obscures much of the intrinsic educational value that a material may potentially bring to an interaction with a learner. [5]

In a bid to address the problem of obscuring the potential role and intrinsic value of materials in investigations of mathematics learning, SHAFFER and CLINTON (2005, 2006) have suggested another approach that draws on elements of ANT to conceptualize the relationship between learners and materials. In particular, SHAFFER and CLINTON (2006) take the ANT notion that when agents, whether human or non-human, act within socio-technical networks the capacity to act is not located in either party but instead emerges from their interaction (SUCHMAN, 2007; LATOUR, 2007; LAW, 2002). Drawing on this notion, they assert that in relation to computing technologies such as TI-Nspire an overt focus on the human side of human-technology relationships may limit understanding of the role technology plays in learning. They note that while "this may not be a problem in a theoretic culture of static inscriptional systems. In a virtual culture based on offloading of symbolic processing, however, using human action to analyse activity obscures the active role tools play" (SHAFFER & CLINTON, 2006, p.289). [6]

While the use of ANT is relatively rare in educational research, Shaffer and Clinton's approach shares a number of common features with a small group of researchers drawing on ANT to investigate a wide range of educational topics (ROTH, 2002; FENWICK & EDWARDS, 2010; GOUGH, 2004; SAMARAWICKREMA & STACEY, 2007; SØRENSEN, 2007). A key common theme in the approaches of these researchers is a focus on the materiality of learning situations without assuming the agency or role of any actors whether human or non-human before examining their local interactions. SØRENSEN (2007) for example, examined physical and virtual materials in primary school classrooms by considering the activity between humans and materials to be a relational effect rather than focusing on the agency of any individual or group of actors. Her analysis describes a situation where both space and time within the classroom are emergent phenomena of the relationships between students, teachers and materials (SØRENSEN, 2007). [7]

Beyond conceptualizing the relationships between humans and non-humans without making *a priori* assumptions about the agency of any actor, another key common feature in studies of learning and educational settings that draw on ANT is the combination of theoretical perspectives. Since by design ANT is more a loose set of ideas rather than a well-defined theory, many researchers choose to simultaneously draw on other theories to inform their work. This reflects the evolving nature of ANT as a perspective on networks of social activity (FENWICK & EDWARDS, 2010). SAMARAWICKREMA and STACEY (2007), for example, drew on ROGERS' (2003) theory of diffusion of innovations in combination with ANT to investigate the adoption of web-based distance learning technologies by university level instructors. Using ROGERS' theory to examine the individual motivations and actions of the instructors and ANT to understand the networks of humans and technology, they analyzed the cases of six Australian universities as they adopted web-based learning technologies (SAMARAWICKREMA & STACEY, 2007). Their finding that successful adoption of technology by instructors had little to do with general comfort with digital technology and was instead influenced by such factors as funding grants and faculty politics illustrates the broad range of inquiries that ANT can be implicated in through careful combination with other theory. [8]

SAMARAWICKREMA and STACEY's (2007) choice to work with a combination of theoretical perspectives is common amongst educational researchers who draw on ANT (FENWICK & EDWARDS, 2010). Returning to SHAFFER and CLINTON's (2005, 2006) approach to conceptualizing the relationship between humans and technology in learning situations, they also combine ANT with other theory. In this case, SHAFFER and CLINTON draw on ANT together with activity theory (COLE, 1998; ENGESTRÖM, 2001; LEON'TEV, 1978; NARDI, 1995; ROTH & LEE, 2007; VYGOTSKY, 1986 [1934]). This approach addresses the major criticism that ANT lacks tools for conceptualizing the internal properties of agents within social networks (ENGESTRÖM, 2001). To address this limitation, SHAFFER and CLINTON (2006) draw particularly on the activity theory notion that all human action including cognition takes place within activity systems that are mediated by tools, whether psychological or technical (LEONT'EV, 1978; VYGOTSKY, 1986 [1934]). With this conceptualization, learning is considered to be an integral aspect of all human activity that necessarily involves tools whether or not technical tools such as educational technologies are involved (SÄLJÖ, EKLUND & MÄKITALO, 2006). [9]

3. Theoretical Perspective

As a theoretical perspective for this study, I follow SHAFFER and CLINTON's (2006) approach by drawing on Actor-Network theory (ANT) in combination with activity theory. Originating with the ideas of VYGOTSKY (1986 [1934]) and LEONT'EV (1978), activity theory is a psychological approach that is particularly concerned with the socially and culturally situated nature of cognition. As a sociocultural approach to understanding cognition, it, "takes as its point of departure the *mediated* nature of human knowledge and action" (SÄLJÖ, 1999, p.151). The theory contends that all human activity takes place within systems that are mediated by cultural tools. These tools can be both internal or psychological and external or technical yielding the notion that all learning involves tools (SÄLJÖ et al., 2006; WERTSCH, 1991). From this sociocultural perspective, tools are understood to mediate all human activity whether we notice them or not and are recognized as the vehicles through which we make meaning (WERTSCH, 1998). This conception of tools, including technologies such as TI-Nspire, as the crucial vehicles with which we make meaning is an important part of the way learning is conceptualized in this study as tool mediated activity. [10]

While both activity theory and ANT are concerned with the mediation of systems of activity, activity theory refers to systems of human activity mediated by tools whereas ANT speaks to networks of humans and non-humans all mediating each other's activity. From an ANT perspective, the properties of technologies in learning situations cannot be ignored or considered transparent since both they and the humans that use them mediate each other (LATOUR, 2007; LAW, 2002; SHAFFER & CLINTON, 2006). Instead, ANT focuses on the ways in which socio-technical networks form as humans and non-humans interact and their practices stabilize (LATOUR, 2007). These networks are composed of relations of network-objects themselves enacted by nested networks of humans and non-humans (LAW, 2002; LAW & MOL, 2001). In the case of this study, for example, TI-Nspire is treated as both a material object and a network-object. As a network-object it is an element of classroom socio-technical networks that is enacted through nested networks that include its developers, the teachers and students who use it, electronics, software, and mathematical knowledge. Network-objects such as TI-Nspire become what LATOUR (1990) refers to as "immutable" as the networks that form them become stable. While network-objects stabilize in the context of patterns of relations, the networks themselves remain fluid (LATOUR, 1990). In this fluid space, the relations between network-objects constantly adapt as new elements emerge or existing elements reconfigure but throughout this fluidity, there is by necessity continuity. Otherwise, networks cease to remain intact, "If everything is taken apart at the same time the result is rupture, the loss of shape-continuity, the loss of identity. The result is more likely to be the creation of an alternative object" (LAW, 2002, p.99). In these cases, network-objects become new entities such as a phonebook being repurposed as a doorstop or a bolt dissolving into the car it holds together. Drawing on ANT conceptions of socio-technical networks of humans and non-humans, and the activity theory understanding of cognition as tool mediated activity, in this study I examine classrooms using TI-Nspire. This examination is at a scale in which the technology is viewed as a network-object while recognizing that it and other implicated network-objects are themselves enacted through complex nested networks. [11]

4. Method

To develop an understanding of the ways TI-Nspire is used in classrooms, I observed and interviewed two teachers who regularly include the technology as part of their instructional practices. These teachers were chosen because they are both fluent users of the technology who make extensive use of it in their classrooms but have distinct teaching and technology use backgrounds. One teacher is an experienced mathematics educator who has worked with graphing calculators for more than ten years while, at the time of the study, the other teacher was new to teaching mathematics but had a background in computer programming and teaching technology. Choosing teachers with a high level of technical literacy afforded me access to contexts where the technology was embedded in many mathematics education practices but, by the same token, such levels of technical fluency are likely not present in most classrooms and this limits my view of the ways TI-Nspire is used. [12]

First, I conducted audio-recorded interviews using a semi-structured schedule that focused on the teachers' use of TI-Nspire and their experiences with technology in the classroom. I drew on the work of MISHLER (1986, 2004) and WEISS (1995) to guide the interview process and strove for conversations that were informal and flexible in nature. Following these initial interviews, I observed a series of five sessions in a ninth grade class taught by each teacher. During the five sessions in each class, I followed a complete teaching unit. In one class the unit involved the teaching of the algebraic skills necessary to perform operations such as simplification on binomial expressions. In the other class, the unit focused on working with data to produce graphs and functions to model trends. I chose to follow a complete teaching unit in each class so that I would have the opportunity to observe both when TI-Nspire was used as well as when it wasn't. I chose ninth grade classes because in this particular school, this was the grade level at which students either purchased or were given a TI-Nspire handheld to use rather than only having access to the technology during class time. This situation offered me the interesting opportunity of observing students who were relatively new to the technology and yet had unfettered access for developing fluency with it. [13]

While observing the classes, I recorded the activity with a video camera from the back corner of the classrooms. In general, I followed the teachers with the camera since my intention for the classroom observations was to concentrate on the ways they included TI-Nspire in their instructional practices and situated the technology for their students. This focus on the teachers guided the majority of the in-camera editing decisions made about where to focus recording but I also made efforts to maintain a wide view as much as possible using panning and zooming sparingly. As DERRY et al. suggest, while a certain amount of pan and zoom may be needed to get a detailed view of activities of interest, "too much selection at recording time may rule out later lines of analysis" (2010, p.48). Drawing on this principle while concentrating my in-camera selection decisions on the teacher, I constantly considered the balance between recording detailed views of teacher activities such as writing on the board or interacting with an individual student and maintaining an impression of the activity in the classroom as a whole. Following each observed session, I invited the teachers to participate in debriefing interviews to help unpack the events that took place and to gain more insight into the decisions made about when and how TI-Nspire was used. [14]

Once interviews and observation had been completed, I transcribed and added the interview recordings and the observational videos to the qualitative analysis software package *Transana* that allows efficient organization and analysis of multiple media sources (WOODS & FASSNACHT, 2009). Within *Transana* each recording and transcript pair was synchronized so that sections identified in one medium would automatically correspond with the same sections in the other (see DEMPSTER & WOODS, 2011 for a detailed description of a similar process). This freedom to move between recording and transcript while maintaining synchronization afforded flexibility to the analytic process during which multiple passes of each interview and video-recording were made. While I analyzed the interviews and observational videos, I also examined artifacts such as digital documents created by the teachers to load onto TI-Nspire and worksheets collected from the observed classrooms. [15]

As an approach to the analysis of the collected multimodal data, I drew on interaction analysis (JORDAN & HENDERSON, 1995). This approach shares many of the same or similar theoretical assumptions that are to be found in this study. In particular, the approach assumes "that knowledge and action are fundamentally social in origin, organization, and use, and are situated in particular social and material ecologies" (p.41). This basic assumption is shared by both activity theory and ANT and forms a key element of the theoretical perspective of this study. From this underlying assumption, interaction analysis suggests a number of ways of working with, in particular, video recordings to analyze ethnographic data. These methods include creating content logs that outline the activity on a recording as soon as possible having recorded an observational session and conducting collaborative viewings with other researchers (JORDAN & HENDERSON, 1995). Drawing on these suggestions, I assembled content logs following each interview or observed session and at least one viewing of the recordings was made in collaboration with another researcher. [16]

Drawing on interaction analysis procedures in concert with the theoretical perspective developed by the combination of ANT and activity theory, I examined the interviews with teachers and students for discussion of the ways they perceive their practices to have changed in relation to TI-Nspire. Using the themes identified from this analysis, I then examined the classroom and lunchtime activity session video-recordings along with collected artifacts for patterns of relations between human and non-human agents that relate to the use of TI-Nspire. This analysis drew on the work of several ANT researchers concerned with the spatiality of socio-technical networks (LAW, 2002; LAW & MOL, 2001; SØRENSON, 2007). These researchers describe the socio-technical networks that are enacted through the practices of human and non-human agents in terms of "fluid spatiality." They suggest that the shape of socio-technical networks is constantly adapting and is never fixed but, importantly, "while the connections which make a shape invariant in fluid space change shape, they do so *gradually* and incrementally" (LAW & MOL, 2001, p.6). Paying attention to the continuity of network-objects within fluid socio-technical networks, I attended to the patterns of relations in the classrooms looking specifically for gradual formations involving TI-Nspire. I then mapped these patterns of relations to produce a snapshot of the fluid networks as they were enacted through the activity of the human and non-human agents in the classrooms. [17]

5. Findings

From the analysis of the interviews, observational recordings and artifacts I identified and mapped patterns of socio-technical relations involving TI-Nspire. This mapping resulted in a geography of connections with three key areas representing different aspects of the classroom socio-technical networks that were identified by participants as having adapted in relation to TI-Nspire.

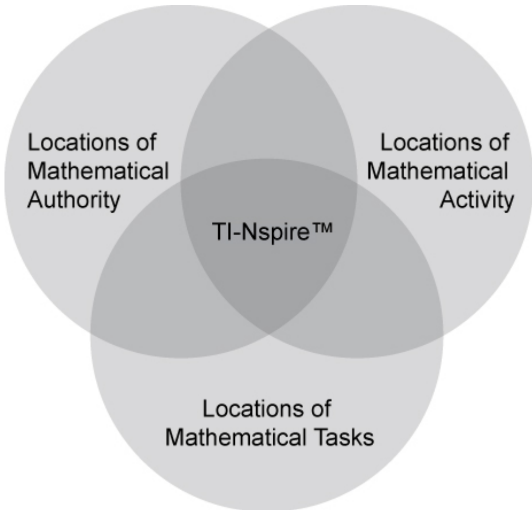

Figure 2: Key socio-technical network areas [18]

These areas: *locations of mathematical authority*, *locations of mathematical tasks*, and *locations of mathematical activity* are illustrated in Figure 2. In the following sections each network area will be addressed and patterns of relations between implicated network-objects in the classrooms will be discussed. [19]

5.1 Locations of mathematical authority

One key area of the classroom socio-technical networks in relation to TI-Nspire that was identified during interviews involves locations of mathematical authority in the classrooms. Both teacher and student participants spoke about the role of TI-Nspire as a source of mathematical guidance and way of checking answers. In particular, teacher participants described students' asking TI-Nspire to answer questions rather than coming to them, a phenomenon that they encouraged and has been observed by a number of researchers in relation to other technologies (MONAGHAN, 2004; PIERCE, STACEY & WANDER, 2010). During a debriefing session, for example, one teacher spoke about how he had encouraged students to go to their TI-Nspire when they were stuck on a problem involving the application of a formula to determine the volume of a solid:

> "So the minute [the student] writes down the volume formula he's like 'oh is that the right one?' Like he wants to ask me, is that the right one, am I right? And we started to make some progress at the beginning of the year, like I said 'when solving equations don't ask me, check [TI-Nspire], it'll tell you if its right or not'" (teacher *two*). [20]

This practice of suggesting to students that the technology could be a source of mathematical help and verification was also apparent during the observed classes. Typifying the phenomenon, in one lesson that involved a period devoted to completing a worksheet in pairs, the other teacher participant instructed the class to, "Work through it, talk with each other, use the handheld to check what you're thinking to see if its giving you what you expect" (teacher *one*). As this teacher often did, he reminds the class that TI-Nspire can give them definitive answers and help them to find misconceptions in their mathematical thinking. [21]

These practices reveal new patterns of relations between teacher and students in terms of the sources of mathematical authority in the classroom. Speaking in an interview about the resources students have for checking their mathematical reasoning, one teacher noted,

> "They do see this [TI-Nspire] as being in the hierarchy of who you trust. Like they'll trust the textbook, they'll trust the teacher, they'll trust the handheld right? They'll be a little sceptical of their partners but willing to listen" (teacher *one*). [22]

With the introduction of a technology that can provide trusted answers to a broad range of mathematical questions, the role of the teacher as a source of mathematical authority changes as students can turn to the technology to resolve mathematical problems or disagreements with others. [23]

A network-object that directly relates to the role of the teacher and TI-Nspire in terms of locations of mathematical authority is the textbook. Similar to the way students were encouraged to use TI-Nspire to check answers before asking their teacher, they also tended to use the technology instead of the answer pages at the back of their textbook. Speaking about this behavior in an interview, one of the teachers offered, "They've realized the limitations with the textbooks, that their answers are wrong in the back of the book. Well there's a certainty and a trust to this [TI-Nspire]—kind of that the answers are right" (teacher *one*). The teacher indicates that he has noticed his students choosing to verify answers with TI-Nspire because it is more reliable than the back of their textbook. This practice was observed in the classrooms with both teachers encouraging the use of the technology to check answers by verifying each component operation used in a solution. During one class, the same teacher described some benefits of using TI-Nspire to verify answers telling his students:

> "The back of the book lets you know if your answer is right. It doesn't necessarily know where your thinking went wrong ok? So you're not totally lost in space if you don't have a TI-Nspire. If you're understanding this stuff and you're confident and you're not making silly numeric mistakes. I want you-, Each question you do check the back of the book. I don't want you doing 15 questions all wrong and then realising after 15 you did them all wrong ok? Those of you with TI-Nspires, you don't need the back of the book. You check each transformational move that you make, so each equivalence transformation, write it down, put it in your handheld and see what you get ok? So you'll know not only if your answer is right, you'll know if each move is appropriate" (teacher *one*). [24]

By offering the possibility to check each step of a solution to a problem, the teacher asserts that TI-Nspire affords students much more information than the correct answer at the back of a textbook can provide in isolation. It can act more as a guide than as a simple arbiter of correct answers. Reflecting this advantage, both teachers encouraged their students to work with the technology and their textbook by taking questions from the book but turning to TI-Nspire for guidance about mathematical concepts and procedures. Speaking about the benefits of this practice during an interview, one teacher explained:

> "I think the TI-Nspire allows them to play around with partial understandings much more comfortably than the textbook. You need to fit yourself into the correct ways that the textbook proposes you do things and some kids just can't find it in themselves to do that. So they can still be incorrect and playing around with their ideas and trying to resolve them with the TI-Nspire with feedback all the time. The only feedback you get with the textbook is 'I'm wrong'" (teacher *one*). [25]

This teacher notes that like the back of the textbook TI-Nspire can be used to check if an answer is correct. He asserts that unlike the back of the textbook, however, TI-Nspire is more flexible giving students more latitude to explore mathematical ideas. The teacher suggests that when students are working on questions from their textbook, the technology becomes a partner in the activity. Similar to the relationship between teacher, student and TI-Nspire in terms of locations of mathematical authority, the socio-technical network of student, textbook and TI-Nspire affords new possibilities for learning that would be difficult to realize with student and textbook alone. [26]

5.2 Locations of mathematical tasks

We have just seen how new patterns of relations were formed with TI-Nspire as a locus of mathematical authority in the classrooms. Now we will look at the ways in which the mathematical tasks that were assigned to students were adapted. Speaking to such changing practices, teacher *one* noted that by affording students a more flexible way to work through problems, TI-Nspire had changed the types of questions he felt comfortable assigning. Talking specifically about assigning homework, he suggested:

> "It's changed the nature of the homework that I give because if I'm assuming a kid has access to this [TI-Nspire] at home what I can envision them doing is very different than if all they have is their textbook and a notebook" (teacher *one*). [27]

Similarly, the technology also changed the way the other teacher gave assignments. Instead of handing out a paper worksheet or assigning questions from the textbook, teacher *two* often created self-contained digital documents that he then distributed to each student's TI-Nspire (see Figure 3).

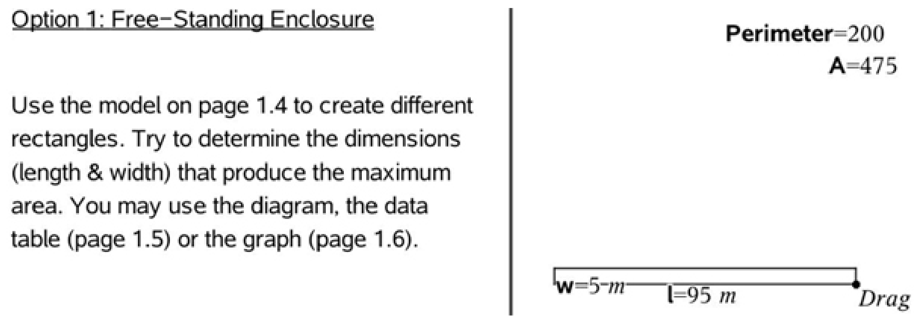

Figure 3: Two pages from a teacher created TI-Nspire digital document [28]

These digital documents contained pages such as those presented in Figure 3. Each page contained different elements of an activity such as instructions, questions, calculation, tables, graphing, and space for recording answers. Once students had completed all the pages of an activity, the teacher could digitally collect their work so that he could examine it on his own TI-Nspire or using a computer based version of the technology. During an interview, the teacher expressed a preference for this approach over the more traditional worksheet or questions from the textbook saying:

> "I kind of actually prefer to have [digital documents] cause I can open them up. I don't have to cart around like this stack of papers. I can just cart around the files, they're fairly small so whether it be on the handheld or on the computer, I can just look at what they've done" (teacher *two*). [29]

While here the teacher focuses on pragmatic reasons for assigning digital documents instead of using worksheets or the textbook, during a debrief after an observed class he spoke about how using digital documents changed his instructional practice. Discussing a session in which students were given class time to work with a data set that described life expectancy for males and females based on year of birth, the teacher spoke about how he had approached the activity before TI-Nspire:

> "What I've done before is I would have given them an instruction sheet. It's a double-sided sheet of paper. There's a graph of the men's data so they didn't actually plot the data or use the table of values. There was the graph, it asked them to draw the line of best fit, it asked them to make the predictions on the data. The back side was the women's, draw the line of best fit, make the predictions in the data like the years or whatever that I've used and then the end of that activity I actually had them do it on

> [an earlier graphing calculator model], graph it and have the calculator determine the line of best fit and then we just compared the answers. So we said ok well this is the answer you got, the line the calculator gave us, are they close, are they different? And then we actually from there went about talking about how to create the line and come up with the equation using a couple of the data points" (teacher *two*). [30]

When assigning the activity before having access to TI-Nspire, the teacher used to ask students to graph the male and female life expectancy data sets on paper and then draw lines of best fit. Then he had students enter the data into older graphing calculators that do not have all the features of TI-Nspire. With these more basic calculators, the students then used linear regression to produce lines of best fit. The students could then compare their drawn lines of best fit to those produced by the calculators. Since class time was limited and the teacher's goal was to have students explore the concept of modeling trends in data through lines of best fit, he did not see the approach as ideal. Graphing the data on paper took a long time but allowed students to interpret and draw their own lines of best fit while using the older calculators for graphing took less time but did not afford students the chance to create their own lines of best fit. TI-Nspire, however, allows much of the manual work of data entry to be eliminated while still providing students the opportunity to create their own graphs and lines of best fit using its graphical functionality. By providing students with a digital document containing all the necessary data and instructions, the teacher was able to make what he considered to be much better use of the available class time while still focusing the activity on the interpretation of data. Particularly by reducing the time required for students to perform tasks, the relationship between student and TI-Nspire opens up new instructional possibilities that allow teachers and learners to focus on mathematical concepts. In response to these possibilities, new patterns of relations were found in the two classrooms between such network-objects as the textbook and TI-Nspire that showed ways that the classroom socio-technical networks adapted in terms of locations of mathematical tasks. [31]

5.3 Locations of mathematical activity

While TI-Nspire may open up new instructional possibilities and ways of working, it was not the only location of mathematical activity observed in the classrooms. It was not even the only digital technology used. In the school that this study was conducted, the teachers had dynamic geometry software such as *The Geometers Sketchpad*™, and statistical and graphing software such as *Fathom*™ and *Tinkerplots*™ at their disposal. As is the case in many schools, however, this software was hosted on computers in a lab that required classes to change classrooms. By contrast, TI-Nspire is a mobile handheld device that can be used in any classroom but has drawbacks particularly in terms of the limited size of its screen and keyboard. These factors meant that the teacher participants had to choose when to use TI-Nspire and when to use the computer lab. Discussing this relationship, one teacher talked about how TI-Nspire relates to the computer lab:

> "It's nice that there's a single tool that the kids can use for pretty much all the math that we're doing right now. So if I can't get into the computer lab we can still do

> Fathom or Tinkerplots things with [TI-Nspire]. Or if we can't get in the lab and use Sketchpad there are dynamic geometry things we can do with [TI-Nspire]. So the fact that you've always got a computer lab at the ready without having to book it, march the kids into a different location is really nice. So that this fits itself to the lesson rather than the lesson having to fit itself to the technology" (teacher *one*). [32]

Because TI-Nspire is a handheld technology it is inherently more flexible than a fixed computer lab in terms of where and when it can be used. As the teacher notes, it does not necessarily need to be booked and unlike computer labs which require moving the class to another location can be used for a short part of a lesson. During the observed classes, both teachers used TI-Nspire at times for short periods of focused activity that might have been impractical with a computer lab. For example, guiding the class through the simplification of a polynomial by writing on the blackboard and describing his actions, one teacher turned to TI-Nspire during a discussion with two students about what the next operation should be. The students had different views of how the expression could be operated upon and the teacher asked them to put it in to the technology saying, "For those of you with TI-Nspires just try putting that in and hit enter and see what it gives you back" (teacher *one*). This kind of quick use of the technology would not be practical if the class had to move to a computer lab. [33]

Beyond having the flexibility of a handheld device that can be easily transported and used on an ad-hoc basis during a lesson, TI-Nspire was also seen by the teachers as supporting richer mathematical conversation than traditional computer labs. One teacher in particular indicated that part of his decision when choosing TI-Nspire over taking his class to the computer lab was informed by the idea that it's handheld nature lent itself to supporting or at least not hampering conversation between students. He notes that, "The computer lab is a hideous setup where kids are facing the wall around the outside and it's a bad setup for learning, it's all about computers. The nice thing about [TI-Nspire] is it's not all about the handhelds" (teacher *one*). Despite the perceived beneficial attributes of TI-Nspire such as those the teacher refers to, many of its functions such as dynamic geometry and graphing overlap with features of software often found in school computer labs. The very size and portability of TI-Nspire that makes it useful in some situations may render it clumsy and difficult to use in others. The opinions and practices of the teachers show that a relationship exists between TI-Nspire and the computer lab. While in many cases TI-Nspire was chosen over the computer lab, it did not totally replace it and the socio-technical networks in the classrooms adapted to accommodate both technologies. [34]

Another digital technology in the classroom that has a relationship with TI-Nspire in terms of locations of mathematical activity is the interactive whiteboard. It displays a projected computer screen and allows users to interact by touching and writing directly on the image. Teachers can project a computer software emulator version of TI-Nspire onto an interactive whiteboard and then manipulate a large image of the handheld (see Figure 4).

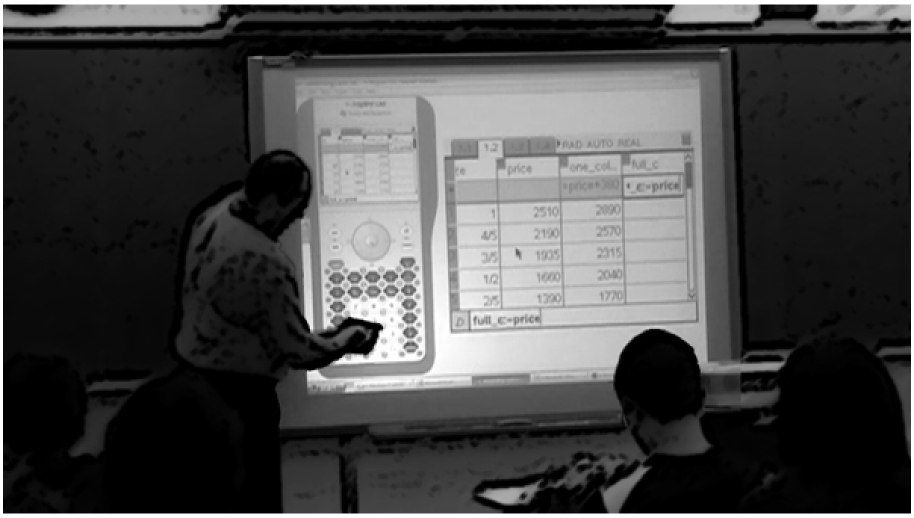

Figure 4: Teacher using interactive whiteboard with TI-Nspire [35]

Despite this feature of interactive whiteboards that allow users to manipulate a large projected version of TI-Nspire, in one of the observed classrooms the teacher preferred to use a blackboard as the primary location of shared mathematical activity. In this classroom, the blackboard was used in combination with TI-Nspire and the translation of mathematical notation between the technology and backboard was a key component of most of the observed sessions. This teacher described how he had at first frequently used an interactive whiteboard when he first introduced TI-Nspire to his classes but then changed his practice saying,

> "I used it a lot at first. I quite enjoyed using it, I use it less now. I don't like to use it as demo because as soon as the lights go off its like it's a movie and the kids are just like this [sits back in chair and folds arms]" (teacher *one*). [36]

In the other classroom, an interactive whiteboard was often used in combination with TI-Nspire instead of the blackboard. It was the primary location of shared mathematical activity in this classroom and was integral to the way TI-Nspire was used. Describing his rationale for the arrangement, the teacher described, "It is so important for them [the students] to be able to have access to it [the interactive whiteboard] to be able to follow along. It just makes it a lot smoother" (teacher *two*). By using an interactive whiteboard in combination with TI-Nspire, the teacher demonstrated ways of working and discussed activities that in his class were almost always assigned as self-contained digital documents. In addition, students could and often did come up to the front of the class and share ways they had approached problems or ways of working with TI-Nspire. For example, during an observed session the teacher asked a student to use the interactive whiteboard to show the class how she arrived at a solution to a problem:

Teacher says:	Go head punch it in on my calculator. As [student] punches it in I'm going to describe what she's doing.
Student inputs:	$100=\frac{\pi \cdot r^2 \cdot 6}{3}$
TI-Nspire returns:	$100=2 \cdot \pi \cdot r^2$
Teacher says:	All right so the very first thing is just to enter the formula and again it did simplify for us because six divided by three is two.
Student inputs:	$Ans/2$
TI-Nspire returns:	$50=\pi \cdot r^2$
Teacher says:	So the next step [student] did was to divide by two and she's got 50 is equal to pi times r squared. [37]

Thus, using the TI-Nspire projected on the interactive whiteboard, the student was able to replicate the work she had done on her handheld. This allowed the class to discuss her approach to solving the problem without having to work with a mediator such as a blackboard that would require them to translate between TI-Nspire mathematical representations and hand-written forms. [38]

A theme that runs through the patterns of relations between TI-Nspire and other network-objects such as the blackboard and interactive whiteboard in terms of locations of mathematical activity is the crucial connection between the technology and paper/pencil work. The importance of this relationship is also indicated by the large amount of mathematics education research that focuses upon the interaction between technological and paper/pencil mathematical activity (ARTIGUE, 2002; CHAPPEL & KILLPATRICK, 2003; DRIJVERS & KIERAN, 2006; KIERAN & SALDANA, 2005; TALL, SMITH & PIEZ, 2008). In the observed classrooms, students worked with both paper/pencil and TI-Nspire collaboratively. There were, however, marked differences between classes that relate directly to the use of such network-objects as paper worksheets, textbooks, self-contained digital documents, blackboards, and interactive whiteboards. In the class where assignments were most often given via paper worksheets and the blackboard was the primary medium for sharing with the group, students tended to work predominately with paper/pencil with TI-Nspire acting as a partner in their activities. In the class where most assignments involved self-contained digital documents and sharing with the group took place on an interactive whiteboard, TI-Nspire tended to be the focus of student mathematical activity. [39]

Each teacher had distinct impressions of how TI-Nspire and paper/pencil could be useful as parts of their instructional practices. As is the case with many of the pedagogical views teachers have, these intentions shaped the role the technology had in their classrooms (PIERCE, BALL & STACEY, 2009). During interviews one teacher in particular spoke often about resisting the technology becoming the focus during lessons. Discussing his choice not to find or create digital documents and distribute them to his students, he explained:

> "The documents I haven't used as much as I thought I would. And I don't think its because there aren't documents out there that are good. It's just that I don't want it to be about the documents, the lessons or the handheld. You know I would prefer it to be in the background and the kids grab it when they need it" (teacher *one*). [40]

This teacher believed strongly that TI-Nspire should be one of many tools available to students but that most mathematical activity should be on paper/pencil. Sharing the view of a number of mathematics education researchers (DRIJVERS, 2000; PIMM, 1995; STACEY, 1997), that handing-off procedural tasks to technology may actually make conceptualizing mathematical concepts more difficult, the teacher also expressed concern about TI-Nspire becoming a black-box. He described his fear of TI-Nspire becoming an opaque computational machine into which problems go and solutions come out without any indication of the processes that have been performed. This motivated him to de-emphasize the importance of the technology in his classroom, instead choosing to focus mathematical activity on paper/pencil. [41]

The other teacher whose class was observed, had a distinctly different view and spoke most often about the advantages of TI-Nspire being the primary location of mathematical activity. Speaking during a debriefing session about a class in which he had asked students to create a number of graphs so that they could be compared, he offered:

> "I don't think I would have got that discussion necessarily about the different points of intersection for the male and female [datasets] today if I didn't have the technology. Cause what would have happened is with, I don't know what did we have there 20 data points, some of the kids it would take them half an hour to graph 20 data points. So by the time they get the one graph created and we get that line drawn that's almost the entire period right? So you can spend a period let's say creating graphs but now if you want to get through the graphs and just do talking about it and analysing it and comparing it, it's so much easier to do in an instant have the graph and now let's discuss" (teacher *two*) [42]

For this teacher, TI-Nspire made it possible to have more discussion and to address more concepts than would be possible with paper/pencil. He saw these advantages as outweighing concerns of black-box effects or the technology becoming the focus of mathematical activity. In his classroom, the primary location of mathematical activity was TI-Nspire with the role of paper/pencil greatly reduced even to the point that students often took notes on the technology. This arrangement of the technology and paper/pencil is distinctly different to the arrangement preferred in the other teacher's class and shows some of the range of ways that socio-technical networks form in relation to TI-Nspire and locations of mathematical activity. [43]

6. Discussion

By examining the activity in classrooms where TI-Nspire is used, the findings of this study illuminate ways that patterns of relations between teachers, students and classroom materials adapt with the introduction of handheld technologies. While only those adapted relations that participants expressed in their interviews were discussed, this subset of the enormously complex set of mediators in classrooms where handheld technologies are used shows the interconnectedness of network-objects such as the teacher, the textbook, worksheets, the computer lab, the board, paper/pencil, handheld technology and students. In Figure 5, the connections between these network-objects that were identified as having formed in relation to TI-Nspire are illustrated.

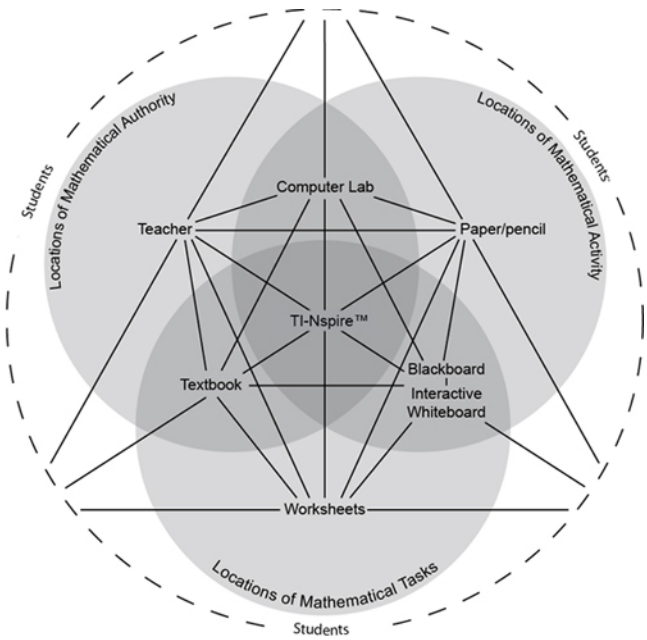

Figure 5: Geography of classroom socio-technical networks involving TI-Nspire [44]

This diagram represents a snapshot of the fluid networks in the two classrooms and the network-objects within them. It shows not only the interconnectedness of the socio-technical networks but also the overlapping roles of the network-objects within them. The humans and materials identified in the diagram fall within three overlapping areas that represent the roles they play in classrooms. While an agent such as the teacher, for example, plays a much greater role within the classroom than just being a location of mathematical authority, this is the role identified in terms of the networks formed in the two classrooms in relation to TI-Nspire. [45]

The teacher was not the only agent of the socio-technical networks in the two observed classrooms that acted as a location of mathematical authority. The answers at the back of the textbook, software in the computer lab and TI-Nspire also acted as locations of mathematical authority for students to draw on. This changed the relationship between teacher and student, allowing students to explore their thinking further before asking the teacher for help. PIERCE et al. (2010) also found evidence of shifts in locations of mathematical authority in relation to the introduction of TI-Nspire. They assert that technology capable of being a source of mathematical authority changes the didactic contract between teacher and student and shifts socio-mathematical norms in the classroom (PIERCE et al., 2010). While they speak to the changed relationship between teacher and student in terms of locations of mathematical authority with the introduction of TI-Nspire, the present study adds to this work by identifying other important relationships within classroom socio-technical networks that are also implicated. The textbook in particular, was identified as also acting as a location of mathematical authority whose relationship with students shifted in relation to TI-Nspire. [46]

While the textbook was identified as a location of mathematical authority in the two observed classrooms, it also served as a location of mathematical tasks. Along with paper worksheets, the blackboard and interactive whiteboard and digital documents on TI-Nspire, the textbook acted as a way mathematical tasks were assigned to students. Each of these network-objects afforded the teachers different possibilities in terms of the kinds of tasks they could assign with the network of TI-Nspire and student having distinctly different properties to student and textbook. DRIJVERS and KIERAN (2006) have also spoken to the relationship between technology and the kinds of tasks assigned to students. They assert that when a student undertakes a mathematical task with a computer algebra system there exists a dialectical relationship between that task and the technique they use from which mathematical theorizing emerges (DRIJVERS & KIERAN, 2006; see also KIERAN & SALDANA, 2005). This speaks to the interrelated nature of materials available to students and the kinds of tasks that can be assigned. Findings drawn from the two observed classrooms in this study support DRIJVERS and KIERAN's assertion by suggesting the introduction of TI-Nspire certainly influences the kinds of tasks assigned to students but, in addition, suggest that it influences the relationships between teacher, student and other network elements such as paper worksheets and the blackboard and interactive whiteboard. [47]

Apart from being implicated as a medium for assigning tasks, the blackboard and interactive whiteboard also acted as a location of mathematical activity in the classrooms. Together with the computer lab, paper/pencil and TI-Nspire handhelds, the blackboard and interactive whiteboard served as locations of both individual and shared mathematical activity. While none of these locations replaced any of the others, they were all involved to greater or lesser extents in the mathematical activity of each classroom. The student, teacher, board, paper/pencil, computer software, and TI-Nspire were arranged in different ways with each configuration supporting different activity. As several researchers have suggested, in terms of learning perhaps what is most important is that multiple locations of mathematical activity were available for students to work and share with (DRIJVERS & KIERAN, 2006; KIERAN & SALDANA, 2005). [48]

During the course of this study, I was particularly struck by the relationship between the activity students engage in individually and activity shared by the whole class by means of a blackboard or interactive whiteboard. I found that the materials that participate in this relationship have a distinct role in mediating mathematical activity and that the interaction between students and materials in one location had a particular influence on the other and *vice versa*. In the case of this study, the materials were most often paper and pencil and TI-Nspire for private activity, and blackboard and interactive whiteboard for public activity. The complexity of the relationships among these materials, students and teachers as they engaged in mathematical activity that I found in this study indicates that more focused research with other materials and in other settings would help to further our understanding of this important aspect of classroom practice. [49]

By taking an ANT approach that required me to attend to the interactions between humans and non-humans in the classrooms while consciously trying to limit *a priori* judgments about their roles and agency and by working with both interviews and video-recorded observational data, the findings of this study indicate that socio-technical networks in classrooms using handheld technology operate as a complex interconnected whole. From interactional analysis of the video recordings of the two classrooms, it is particularly evident that the effects of the teachers' decisions to include TI-Nspire as part of their instructional practices were not limited to, for instance, the local patterns of relations between student and technology while completing an activity. These interactions are instead extremely broad, influencing practices as diverse as homework and the use of the computer lab. The findings of this study show as DRIJVERS et al. (2010) suggest, that the didactical configuration of technologies in mathematics classrooms has a profound effect on the mathematical practices within them but also suggest that this is far from a one-way phenomenon. While teachers have enormous influence through their choices of what technological arrangements to use, other agents both human and non-human in the classroom mediate these configurations and are highly interrelated. For instance, the choice to assign activities as digital documents rather than as questions from the textbook may influence the decision to share mathematical activity as a class with an interactive whiteboard and may influence the decision to create digital notes rather than work with paper/pencil. Each pattern of socio-technical relations mediates the others and together they reciprocally shape the geography of the classroom. [50]

References

Artigue, Michel (2002). Learning mathematics in a CAS environment: The genesis of a reflection about instrumentation and the dialectics between technical and conceptual work. *International Journal of Computers for Mathematics Learning*, *7*, 245-274.

Borba, Marcelo C. & Villarreal, Monica E. (2006). *Humans-with-media and the reorganization of mathematical thinking: Information and communication technologies, modeling, visualization and experimentation*. Mahwah, NJ: Springer.

Callon, Michel (1986). Some elements of a sociology of translation: Domestication of the scallops and the fishermen of St. Brieuc bay. In John Law (Ed.), *Power, action and belief: A new sociology of knowledge?* (pp.196-223). Routledge: London.

Chappel, Kelly K. & Killpatrick, Kendra (2003). Effects of concept-based instruction on students' conceptual understanding and procedural knowledge of calculus. *Primus*, *13*, 17-37.

Cole, Michael (1998). *Cultural psychology: A once and future discipline*. Cambridge, MA: Belknap Press.

Dempster, Paul G. & Woods, David K. (2011). The economic crisis through the eyes of Transana. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*, *12*(1), Art. 16, http://nbn-resolving.de/urn:nbn:de:0114-fqs1101169 [Accessed: April 12, 2011].

Derry, Sharon J.; Pea, Roy D.; Barron, Brigid; Engle, Randi A.; Erickson, Frederick; Goldman, Ricki; Hall, Roger; Koschmann, Timothy; Lemke, Jay L.; Gamoran Sherin, Miriam & Sherin, Bruce L. (2010). Conducting video research in the learning sciences: Guidance on selection, analysis, technology, and ethics. *Journal of the Learning Sciences*, *19*(1), 3-53.

Drijvers, Paul (2000). Students encountering obstacles using CAS. *International Journal of Computers for Mathematics Learning*, *5*(3), 189-209.

Drijvers, Paul & Kieran, Carolyn (2006). Reconciling factorizations made with CAS and with paper-and pencil: The power of confronting two media. In Jarmila Novotná, Hana Moraová, Magdalena Krátká & Nad'a Stehlíková (Eds.), In the proceedings of *30th conference of the International Group for the Psychology of Mathematics Education* (pp.473-480). Prague: PME.

Drijvers, Paul & Weigand, Hans-Georg (2010). The role of handheld technology in the mathematics classroom. *ZDM Mathematics Education*, *42*(7), 665-666, DOI: 10.1007/s11858-010-0285-2.

Drijvers, Paul; Doorman, Michiel; Boon, Peter; Reed, Helen & Gravemeijer, Koeno (2010). The teacher and the tool: Instrumental orchestrations in the technology-rich mathematics classroom. *Educational Studies in Mathematics*, *75*(2), 213-234, DOI: 10.1007/s10649-010-9254-5.

Engeström, Yrjö (2001). Expansive learning at work: Toward an activity theoretical reconceptualization. *Journal of Education and Work*, *14*(1), 133-156.

Fenwick, Tara & Edwards, Richard (2010). *Actor-network theory in education*. London: Routledge.

Gough, Neil (2004). RhizomANTically becoming-cyborg: Performing posthuman pedagogies. *Educational Philosophy and Theory*, *36*(3), 253-265.

Hegedus, Stephen J. & Moreno-Armella, Luis (2010). Accomodating the instrumental genesis framework within dynamic technological environments. *For the Learning of Mathematics*, *30*(1), 26-31.

Jordan, Brigitte & Henderson, Austin (1995). Interaction analysis: Foundations and practice. *The Journal of the Learning Sciences*, *4*(1), 39-103.

Kaput, James & Schorr, Roberta (2008). Changing representational infrastructures changes most everything. In Kathleen Heid & Glendon W. Blume (Eds.), *Research on technology and the teaching and learning of mathematics: Vol. 2: Cases and perspectives* (pp.211-253). Charlotte, NC: Information Age Publishing.

Kieran, Carolyn & Saldana, Luis (2005). Computer algebra systems (CAS) as a tool for coaxing the emergence of reasoning about equivalence of algebraic expressions. In Helen L. Chick & Jill L. Vincent (Eds.), *Proceedings of the 29th conference of the International Group for the Psychology of Mathematics Education* (pp.193-200). Melbourne: PME.

Lagrange, Jean-Baptiste (1999). Complex calculators in the classroom: Theoretical and practical reflections on teaching pre-calculus. *International Journal of Computers for Mathematics Learning*, *4*(1), 51-81.

Latour, Bruno (1990). Drawing things together. In Michael Lynch & Steve Woolgar (Eds.), *Representation in scientific practice* (pp.19-68). Cambridge, MA: MIT Press.

Latour, Bruno (2007). *Reassembling the social: An introduction to actor-network-theory*. Oxford: Oxford University Press.

Law, John (2002). Objects and spaces. *Theory, Culture & Society*, *19*(5-6), 91-105.

Law, John & Mol, Annemarie (2001). Situating technoscience: An inquiry into spatialities. *Society and Space*, *19*, 609-621.

Leont'ev, Aleksei N. (1978). *Activity, consciousness, and personality*. Upper Saddle River, NJ: Prentice-Hall.

Meira, Luciano (1998). Making sense of instructional devices: The emergence of transparency in mathematical activity. *Journal for Research in Mathematics Education*, *29*(2), 121-142.

Mishler, Elliot G. (1986). *Research interviewing: Context and narrative.* Cambridge, MA: Harvard University Press.

Mishler, Elliot G. (2004). *Storylines: Craftartists' narratives of identity.* Cambridge, MA: Harvard University Press.

Monaghan, John (2004). Teachers' activities in technology-based mathematics lessons. *International Journal of Computers for Mathematics Learning*, *9*, 327-357.

Nardi, Bonnie A. (1995). *Context and consciousness: Activity theory and human-computer interaction*. Cambridge, MA: MIT Press.

Pierce, Robyn; Ball, Lynda & Stacey, Kaye (2009). Is it worth using CAS for symbolic algebra manipulation in the middle secondary years? Some teachers' views. *International Journal of Science and Mathematics Education*, *7*(6), 1149-1172.

Pierce, Robyn; Stacey, Kaye & Wander, Roger (2010). Examining the didactic contract when handheld technology is permitted in the mathematics classroom. *ZDM*, *42*(7), 683-695, DOI: 10.1007/s11858-010-0271-8.

Pimm, David (1995). *Symbols and meanings in school mathematics.* London: Routledge.

Rogers, Everett M. (2003). *Diffusion of innovations* (5 ed.). New York: The Free Press.

Roth, Wolf-Michael (2002). Evaluation and adjudication of research proposals: Vagaries and politics of funding. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research, 3*(3), Art. 25, http://nbn-resolving.de/urn:nbn:de:0114-fqs0203259 [Accessed: April 12, 2011].

Roth, Wolf-Michael & Lee, Yew-Jin (2007). "Vygotsky's neglected legacy": Cultural-historical activity theory. *Review of Educational Research*, *77*(2), 186-232.

Säljö, Roger (1999). Learning as the use of tools: A sociocultural perspective on the human-technology link. In Karen Littleton & Paul Light (Eds.), *Learning with computers: Analysing productive interaction* (pp.144-161). New York: Routledge.

Säljö, Roger; Eklund, Ann-Charlotte & Mäkitalo, Åsa (2006). Reasoning with mental tools and physical artefacts in everyday problem-solving. In Lieven Verschaffel, Filip Dochy, Monique Boekaerts & Stella Vosniadou (Eds.), *Instructional psychology: Past, present, and future trends. Sixteen essays in honour of Erik de Corte* (pp.73-90). Amsterdam: Elsevier.

Samarawickrema, Gayani & Stacey, Elizabeth (2007). Adopting web-based learning and teaching: A case study in higher education. *Distance Education*, *28*(3), 313-333.

Shaffer, David W. & Clinton, Katherine A. (2005). Why all CSL is CL: Distributed mind and the future of computer supported collaborative learning. In Tak-Wai Chan (Ed.), *CSCL '05: Proceedings of the 2005 conference on Computer support for collaborative learning* (pp.592-601). Taipei, Taiwan: International Society of the Learning Sciences.

Shaffer, David W. & Clinton, Katherine A. (2006). Toolforthoughts: Reexamining thinking in the digital age. *Mind, Culture, and Activity*, *13*(4), 283-300.

Sørensen, Estrid (2007). The time of materiality. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*, *8*(1), Art. 2, http://nbn-resolving.de/urn:nbn:de:0114-fqs070122 [Accessed: April 12, 2011].

Stacey, Kaye (1997). Mathematics—what should we tell the children? *The International Journal of Computer Algebra in Mathematics Education*, *4*(4), 387-390.

Suchman, Lucy A. (2007). *Human-machine reconfigurations: Plans and situated actions*. Cambridge: Cambridge University Press.

Tall, David; Smith, David & Piez, Cynthia (2008). Technology and calculus. In Kathleen Heid & Glendon W. Blume (Eds.), *Research on technology and the teaching and learning of mathematics: Vol. 1: Research syntheses* (pp.207-258). Charlotte, NC: Information Age Publishing.

Trouche, Luc (2004). Managing the complexity of human/machine interactions in computerized learning environments: Guiding students' command process through instrumental orchestrations. *International journal of Computers for Mathematical Learning*, *9*(3), 281-307.

Trouche, Luc & Drijvers, Paul (2010). Handheld technology for mathematics education: flashback into the future. *ZDM*, *42*(7), 667-681, DOI:10.1007/s11858-010-0269-2.

Verillon, Pierre & Rabardel, Pierre (1995). Cognition and artifacts: a contribution to the study of though in relation to instrumented activity. *European journal of Psychology of Education*, *10*(1), 77-101.

Vygotsky, Lev (1986 [1934]). *Thought and language, revised edition*. Cambridge, MA: The MIT Press.

Weiss, Robert S. (1995). *Learning from strangers: The art and method of qualitative interview studies.* New York: Free Press.

Wertsch, James V. (1991). *Voices of the mind: A sociocultural approach to mediated action.* Cambridge, MA: Harvard University Press.

Wertsch, James V. (1998). *Mind as action.* Oxford: Oxford University Press.

Woods, David & Fassnacht, Chris (2009). *Transana v2.41.* Madison. WI: The Board of Regents of the University of Wisconsin System.

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