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Discovering Features of Web-Based Algebraic Tools Via Data Analysis to Support Technology Integration in Mathematics Education

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Abstract

Technological tools available on the Internet can be used to support teachers' understanding of how to teach mathematics to their students. This paper outlines a method for using algebraic tools in mathematics with teachers to help them discover features to facilitate student learning and understanding with the support of statistical software. The teachers first investigate algebraic tools and then analyze features of the tools and how they support or limit student learning. Personal Construct Theory (Kelly, 1955) is used to first help teachers create and self administer repertory grids and then generate dendrograms for cluster analysis. The model described can help others implement technology in a similar manner making use of both web-based applets and statistical software in an authentic context.

Technology is changing how teachers learn how to teach mathematics. Innovative technology that can be used as a tool can allow preservice teachers to experience mathematics by seeing the changes that occur when numbers, shapes, equations or graphs are manipulated or altered. In addition, conjectures can be made and tested allowing for deeper investigations with immediate feedback to mathematical tasks beyond what can be done traditionally with paper and pencil (Pea, 1986). With the advent of video cases, cutting edge software and mathematics websites with interactive applets, such tools can be used to enhance and support traditional instruction (Daher, 2009; Roschelle, Pea, Hoadley, Gordin, & Means, 2000).

Even though there are numerous tools available to support mathematics instruction both free online and through purchase, students are still not learning mathematics with the support of these tools. Smith and Shotsberger (2001) questioned preservice teachers and found that most felt that technology was important in mathematics instruction to help students develop concepts but they were unable to articulate how the technology should be used. In fact, many preservice teachers feel ill-prepared to teach using technology after graduation (Carlson & Gooden, 1999). In addition, university instructors often feel pressed for time and must decide between traditional content and technology (Huang, 2009).

Despite these findings, it is important that educators continue to make an effort to use technology to help teachers learn (Daher, 2009). Al-A'ali (2008) found that 80% of teachers believed using technology in mathematics will improve their students' problem-

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solving abilities. These findings indicate that teachers support the use of technologies with their students. If teachers want to use technologies and believe that technologies will help their students learn mathematics better, universities must provide opportunities to help teachers understand what is available and how to use it. Technologies modeled and demonstrated in university classrooms may help teachers transfer what they learn into practice in relation to their careers and lives (Cobb, 2004; Huang, 2009). Technological tools allow people to focus on ideas that matter; learners are provided with the opportunity "…to make explicit that which is implicit and draw attention to that which is often unnoticed" (Hoyles & Noss, 2009, p. 132). In a study by Lin (2010), pre-service teachers learned computation and conceptual knowledge of fractions in a traditional manner or in a web-based manner. It was found that the group who received web-based instruction was significantly more effective in both computation and conceptual understanding of fractions than those who were taught traditionally. Technologies can help students learn, but they must be implemented and modeled to allow for growth.

Technological tools in mathematics allow learners to investigate their ideas and receive immediate feedback as to the soundness of their conjectures (Bouck & Flanagan, 2010). Then, if the results are not as expected, they can formulate another conjecture and try again. This cannot be done as simply without technology. Technology allows learners to focus more on the relationship between the computation and structure while relieving the need to calculate (Daher, 2009; Hoyles & Noss, 2009). With technology, mathematics can be taught as a subject beyond computation and instead focus on sense making and understanding of how the numbers relate to the concept. Technology allows students to discover patterns or relationships and manipulate graphs and functions to observe interconnectedness of numbers and figures (Blubaugh, 2009). Ellington (2007) found that integrating technology throughout a mathematics course to support connections helped students develop more meaningful classroom experiences.

In order to facilitate how teachers learn to educate using technological tools in mathematics, their experiences must move beyond encountering and exploring mathematics tools (Blubaugh, 2009). Instead, the tools used must be thoroughly analyzed and evaluated with specific emphasis on how the technology supports or limits learning in mathematics: What can the tools do to support learning? How do the tools limit learning? How can mathematical tools be used to improve instruction?

This article describes a practical method to support the use of web-based mathematical tools in the university classroom. A step-by-step framework is provided to support the evaluation of technological tools with the use of statistical software to help others in implementing this method. For the purposes of this article, web-based technological tools are defined as any program, activity or applet accessed through the Internet that can be used to support the understanding of mathematically based concepts.

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Using Technology

Many tools have been developed to help support learning in mathematics; some take a more traditional drill-based approach to learning while others allow learners to investigate conjectures and construct knowledge through interactions (Kurz, Middleton, & Yanik, 2005). With the advent of computers, what learners can do is expanded well beyond what can be done with traditional paper and pencil methods (Pea, 1986), and the use of technology as a tool for learning can be advantageous in mathematics instruction (Lajoie, 1993). Tools enable students to think, problem solve, and focus on task orientation (Al-A'ali, 2008). The tool-based approach is a successful method for enhancing learning and understanding in the mathematics setting (Lederman & Niess, 2000). As such, the tool-based use of technology in mathematics is the driving force behind the technology use described in this article. The goal is to allow teachers to experience mathematical tools that support a deeper understanding of mathematics beyond drill.

Statistical software can support the investigation of online tools, and while data analysis is often left out of undergraduate coursework (Scheitle, 2006), it can undoubtedly be incorporated. It is important to recognize that statistics is not mathematics; they are separate disciplines with different functions and objectives (Cobb & Moore, 1997). Statistical software has the potential to aid university learners in understanding the application of mathematics and statistics; the software can allow users to make statistical inferences without a heavy emphasis on calculations. The software allows users to focus on the interpretation of the results. Most statistical courses are taught in isolation of a specific environment; they are taught in a subscribed way following procedures that are often disconnected to the students themselves (Cobb, 2004). Statistical software can allow learners to move beyond lecture and, instead, apply statistics in a relevant, meaningful way (Scheitle, 2006).

Different open-access web-based tools in mathematics can first be viewed and experienced in the university setting. The tools have the potential to be used by teachers to support their students' understanding in mathematics through active engagement (Al-A'ali, 2008). It is important to understand that the information gathered for analysis will come directly from the individual teachers themselves. They will not evaluate the tools with a predetermined set of characteristics or with a previously developed survey. Instead, the teachers will better understand the uses of the tools by developing features as they see them in relation to teaching and learning. To do this, a method developed out of clinical psychology was used for analysis; it has the ability to showcase the individual's organization of beliefs. Personal Construct Theory (Kelly, 1955) can be used to support the teachers' investigations of web-based tools and the advantages and limitations of the tools with the support of statistical software. This theory is well suited for tool analysis because of its documented sensitivity to the

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individual; it allows the individual to see how they themselves view the academic benefits and hindrances of mathematical tools.

Personal Construct Theory

The primary principle of Personal Construct Theory (Kelly, 1955) is that each person interprets the world like a scientist by making distinctions among concepts and objects through the use of elements and constructs. An element is the object used for analysis; in this article the elements are mathematical web-based tools. A construct is a way of describing the similar and dissimilar features among elements. A construct may be a descriptive sentence or statement such as *shows how changing a variable influences the other variables involved*. The constructs are individually developed and are indicators of cognitive similarities and differences. They are organized and structured and can be distinguished through distances between and among constructs (Walker & Winter, 2007) which are commonly demonstrated through the use of repertory grids that are then used to create dendrograms. These techniques are unique because they allow participants to create and define their own constructs in relation to their personal thought processes (Donaghue, 2003; Neimeyer, 1993; Walker & Winter, 2007). This technique also avoids the complications of using a predetermined survey; since the participants are creating their own constructs, there is no interpretation regarding the meaning of a specific construct.

Beail (1985) developed a five stage technique outlining the procedures when using Personal Construct Theory for analysis. The stages will be briefly described here and then cultivated in the next section outlining the technique. The first stage involves eliciting elements. The second stage includes the elicitation of constructs. The method used involves making distinctions among the elements through pairwise comparisons. The constructs can be provided for or created by the participants. Constructs created by the participants provide the best data, as they are representative of individual thoughts and ideas (Fransella, Bell, & Bannister, 2004). In the third stage, a repertory grid is created and administered. A repertory grid displays the elements and constructs that were created by the participant. The grid arranges elements on one dimension and elicits constructs on another dimension. The subject evaluates the constructs and elements on a numeric scale (Borell, Espwall, Pryce, & Brenner, 2003). The fourth stage is analysis; this stage involves entering and analyzing the grid through statistical means. Specifically, statistical software will be used to create hierarchal clusters through the use of dendrograms for analysis. The final stage is interpretation; the dendrograms are examined and clusters of similarities and dissimilarities are discovered.

Personal Construct Theory has been used in a variety of ways to investigate mathematical thinking and understanding. McQualter (1986) described Personal Construct Theory as an advantageous method for investigating mathematical perceptions. Middleton (1995, 1999) used the theory to investigate curricular and

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motivational influences of middle school teachers. Kurz and Middleton (2006) investigated preservice teachers' understanding of mathematics-based software in relation to student learning and understanding with a specific emphasis on the affordances and constraints of the software. Williams (2001) used the technique to investigate cognitive domains including mathematics.

Employing Personal Construct Theory

Referencing Beail's (1985) procedures, a model is presented to display Personal Construct Theory (Kelly, 1955) in practice with respect to mathematical tools available on the web. This model shows how statistical software can be used in mathematics instruction to help teachers understand the advantages and limitations of specific tools. As a model that uses technology for investigations and for analysis, it will help teachers recognize technology as both a teaching tool and a tool to examine statistical applications for data analysis.

The first stage is the elicitation of elements. For the purpose of this example, the elements can be any web-based tools available to support mathematics instruction. There are many different tools available free online to enhance instruction in mathematics and it is not important for teachers to be exposed to all the technology available. Rather, it is important that they encounter technology to help them build a framework to support its integration (Ellington, 2007). In this article, ten specific elements are used for analysis from five different websites in order to help teachers see mathematics in a deeper, more meaningful manner with a specific emphasis on algebra. Line of Best Fit and Pan Balance - Shapes are accessible through the Illuminations site from the National Council of Teachers of Mathematics (2001) (see Web Resources at the end of the article) (Keller, Hart & Martin, 2001). Algebra Balance Scales and Line Plotter are accessible from the National Library of Virtual Manipulatives and were created by Utah State University (see Web Resources). Algebraic Reasoning and Weigh the Wangdoodles are accessible from Math Playground (see Web Resources). Stop that Creature is accessible from PBS (see Web Resources). General Coordinates, Vertical Line Test, and Maze Game are accessible at Shodor Interactivate (see Web Resources). When selecting the tools, a theme is a valuable element, perhaps tools focusing on a specific topic (e.g., algebra or fractions) and/or tools for a specific grade level (such as middle school). Specific topics make the interpretation of the dendrogram more clear-cut and straightforward. Teachers need plenty of time to investigate whatever elements are selected so they can become familiar with the features of the tools.

The second stage is the elicitation of constructs. This involves comparing and contrasting the given elements through pairwise comparisons. Using two elements at a time, the teachers describe how they are similar and dissimilar: Describe how Algebra Balance Scales and Line Plotter are similar and how they are dissimilar. The teachers continue to make distinctions between the tools selected for investigation in paragraph

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form. For example, when comparing Algebra Balance Scales and Line Plotter, a response might be:

- In Algebra Balance Scales, students use the numbers and letters to build the equation. In Line Plotter, students are given a point and a slope and must determine the line that fits the slope. Both are challenging in that the student must figure it out on their own and there is no computer guidance to help them when they struggle. There is just a kind of "that is not right" statement. They both can get frustrating if you don't know what you are doing wrong and don't have anyone to help you.

- The Algebra Balance Scales applet is more difficult to figure out and makes students really think about what an equation is. To use this applet, students must figure out how the scale, numbers, and variables are interconnected to one another. It takes some time to think and figure out. Line Plotter is a little more self-explanatory. The students already have to know what the slope means and how to find the slope. They could also problem solve to figure out the slope. For example, if it is a negative slope and it goes the wrong way, the computer will prompt them to try again. Also, they must already know that the slope is rise over run. This one is more of a review while Algebra Balance can be used as a tool for introduction and understanding.

Pairwise comparisons should be made with each of the elements. Generally, one or two pairwise comparisons per element will yield enough constructs depending on the thoroughness of the responses.

The third step is the creation and then the administration of the repertory grid. Constructs are entered in the grid and then rated when the grid is administered. Since the teachers are learning both about tools and the application of statistical software, they can create their own personal repertory grid based on their responses to the second stage. Examining their responses to the pairwise comparisons, they find the constructs within the responses. For example, in referencing the response from the second step, the teacher can record the constructs by underlining them. In paragraph two, the constructs may be marked as such:

> The Algebra Balance Scales applet is more difficult to figure out and makes students really think about what an equation is. To use this applet, students must figure out how the scale, numbers, and variables are interconnected to one another. It takes some time to think and figure out. Line Plotter is a little more self-explanatory. The students already have to know what the slope means and how to find the slope. They could also problem solve to figure out the slope. For example, if it is a negative slope and it goes the wrong way, the computer will prompt them to try again. Also, they must already know that the slope is rise over

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> run. This one is more of a review while Algebra Balance can be used as a tool for introduction and understanding.

Some of the constructs may be duplicates from other construct analysis. In the example given, *more of a review* was not underlined because the construct *helps for reinforcing concepts already learned* was used from another pairwise comparison. These two can be considered duplicate constructs in that they are very similar. This is an important consideration for other constructs underlined in this example as well. Constructs may be rephrased for clarity or reworded to remove specificity if needed. One of the advantages of this method is that it is forgiving. If a teacher misses some constructs, chooses very similar constructs, or chooses a statement that may not be considered a construct by someone else, he or she is still able to advance in analysis. It is important that the teacher develop enough constructs for a rich analysis. After the constructs are discovered, a repertory grid should be created. The elements (i.e., web-based tools) should be positioned across the top of the first row; the constructs are located down the first left column (there may be 50 or more). Be sure the teachers remove any duplicate or very similar constructs after the repertory grid is created if they missed some when underlining. After constructing the repertory grid, the teachers complete it using a three-point scale: 1 = construct is not very descriptive of the tool, 2 = the construct is somewhat descriptive of the tool, or 3 = the construct is very descriptive of the tool. This is often called the administrating of the grid. People may rate the constructs dissimilarly; this is not a problem with this method as it is particularized for each individual. Table 1 displays a completed repertory grid.

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Table 1
An Example of a Completed Repertory Grid

	General coord	Vertical line test	Line of best fit	Alg balance scales	Line plotter	Pan balance	Weigh wang-	Algebra reason	Stop that creature	Maze game
For students in upper elementary (grades 4-6)	3	1	1	2	1	3	1	1	3	2
For middle school students (grades 7-8)	2	3	3	3	3	3	3	3	2	3
Strategy must be used to solve	1	2	3	3	2	3	3	3	2	2
Students have to think to solve	2	2	3	3	2	3	3	3	3	3
Students have control over the activity	1	1	3	1	1	2	1	1	1	3
The activity uses strategy	1	2	1	3	2	3	2	3	2	2
Use reasoning to solve	2	3	3	3	2	3	3	3	3	2
Use algebra to solve	1	1	1	3	2	3	3	3	3	1
Guess and check can be used	2	3	2	1	2	2	3	2	3	1
Shows how changing a variable influences the other variables involved	1	1	2	2	1	3	3	3	2	1
It is a like a game	1	1	1	2	1	3	1	2	2	3
Requires logic to solve	2	2	2	3	2	3	3	3	3	2
Involves using the coordinate system	3	3	3	1	3	1	1	1	1	3
Uses adding and subtraction	2	1	1	3	1	3	3	3	3	1
Using multiplying and dividing	1	1	1	3	1	2	3	3	3	1
Has action to keep the students motivated	1	1	2	2	1	3	1	1	2	3
It is exciting	1	1	2	2	1	3	2	2	3	3
Students must problem solve to find the solution	2	1	2	3	2	2	3	3	3	2
Challenge level can be adjusted	1	1	1	1	1	1	1	3	1	3
Uses algebraic systems	1	1	2	3	1	3	3	3	3	1
Holds the students' interest	1	1	2	2	1	3	2	2	2	3
Motivates students to try hard	1	1	2	1	1	2	2	2	3	3
It is interesting	1	2	2	2	1	2	2	2	1	3
It is challenging	1	1	2	3	2	2	3	3	2	2
Students must try and find a pattern	1	1	1	2	2	3	2	3	3	1
Students must figure out how numbers or objects are connected to one another	1	1	1	3	1	3	3	3	2	1
Uses all four operations (add, subtract, multiply and divide)	1	1	1	3	1	3	3	3	3	1
It is a spatial activity	3	3	3	2	2	1	2	1	1	3

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Table 1 (continued)
An Example of a Completed Repertory Grid

	General coord	Vertical line test	Line of best fit	Alg balance scales	Line plotter	Pan balance	Weigh wang-	Algebra reason	Stop that creature	Maze game
It is numbers based	2	2	1	3	1	2	3	3	3	1
It is fun to play	1	2	3	2	2	3	2	2	2	3
It lets students learn math in a better way than using a textbook	2	3	3	3	3	2	3	2	2	3
It is easy to figure out a solution	3	1	2	1	2	1	1	1	2	3
The activity is frustrating	1	1	1	2	1	2	3	3	2	1
Students might give up because the game is too hard	1	1	1	2	1	1	3	2	1	1
The output changes and the student must find out what is happening	1	2	1	1	2	3	2	3	3	1
Students examine how pictures and numbers relate to one another	1	1	1	3	1	3	3	3	1	1
Students must solve numeric values	1	1	1	3	1	2	3	3	3	1
It is like a puzzle	2	1	2	2	1	3	3	3	2	2
Students might stare at the screen for a long time just thinking	1	1	2	3	1	3	3	3	2	1
The graphics are very good	1	1	2	2	1	2	2	2	1	2
Students can have multiple tries	3	3	3	3	3	3	3	3	3	2
There is only one set of numbers for the solution	3	1	3	1	3	3	3	3	3	1
The solution involves using numbers that work together as a team	2	3	2	3	2	3	3	3	2	2
The student can just click to find a solution	1	1	2	1	1	1	1	1	2	2
Student has to figure out what is relevant for the solution to be found	1	2	2	2	1	2	1	3	1	1
There are coordinates to locate	3	1	2	1	3	1	1	1	1	3
Meaning is found through interactions	2	2	3	3	2	2	1	1	2	1
Students get immediate feedback	3	3	3	2	3	3	2	2	3	2
Self-motivating	1	2	3	2	2	3	3	3	3	3
Numbers and letters are used	1	1	1	3	1	2	3	2	1	1
Slope is used or discovered	1	2	3	1	3	1	1	1	1	1
Scale, variables and numbers are used	1	1	1	3	1	3	3	3	1	1
Helps for introducing	2	3	3	3	1	2	2	2	3	2
Helps for reinforcing concepts already learned	3	3	3	2	3	2	3	3	2	3

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After the entire repertory grid is completed, the fourth stage is analysis which calls for the use of statistical software. Statistical software such as Statistical Package for Social Sciences (SPSS) can be used for data analysis. SPSS has the capacity to quickly create hierarchical clusters by displaying dendrograms based on the repertory grid data. After the data are entered in SPSS, the teachers should analyze the results.

Steps in Analyzing

Select Analyze
Then classify
Then Hierarchical Cluster (Opens the Hierarchical Cluster Analysis window)
Select web-based tools and transfer them into the Variables section

It is important to note that the order in which the web-based tools are entered determines the way that they will be numbered in the dendrogram output. If you want the tools' numbers to align with the output, the tools must be transferred in that order.

Steps Continued for Analyzing

In the *Hierarchical Cluster Analysis* window select Dendrogram near the top of the window.
Unselect Icicle
Select Continue
When the *Hierarchal Cluster Analysis* window is displayed again, select the Method button on the right.
Select Ward's Method for the Cluster Method.
Select Continue
Click OK

See Figure 1 for the dendrogram created through the analysis of the provided repertory grid in Table 1.

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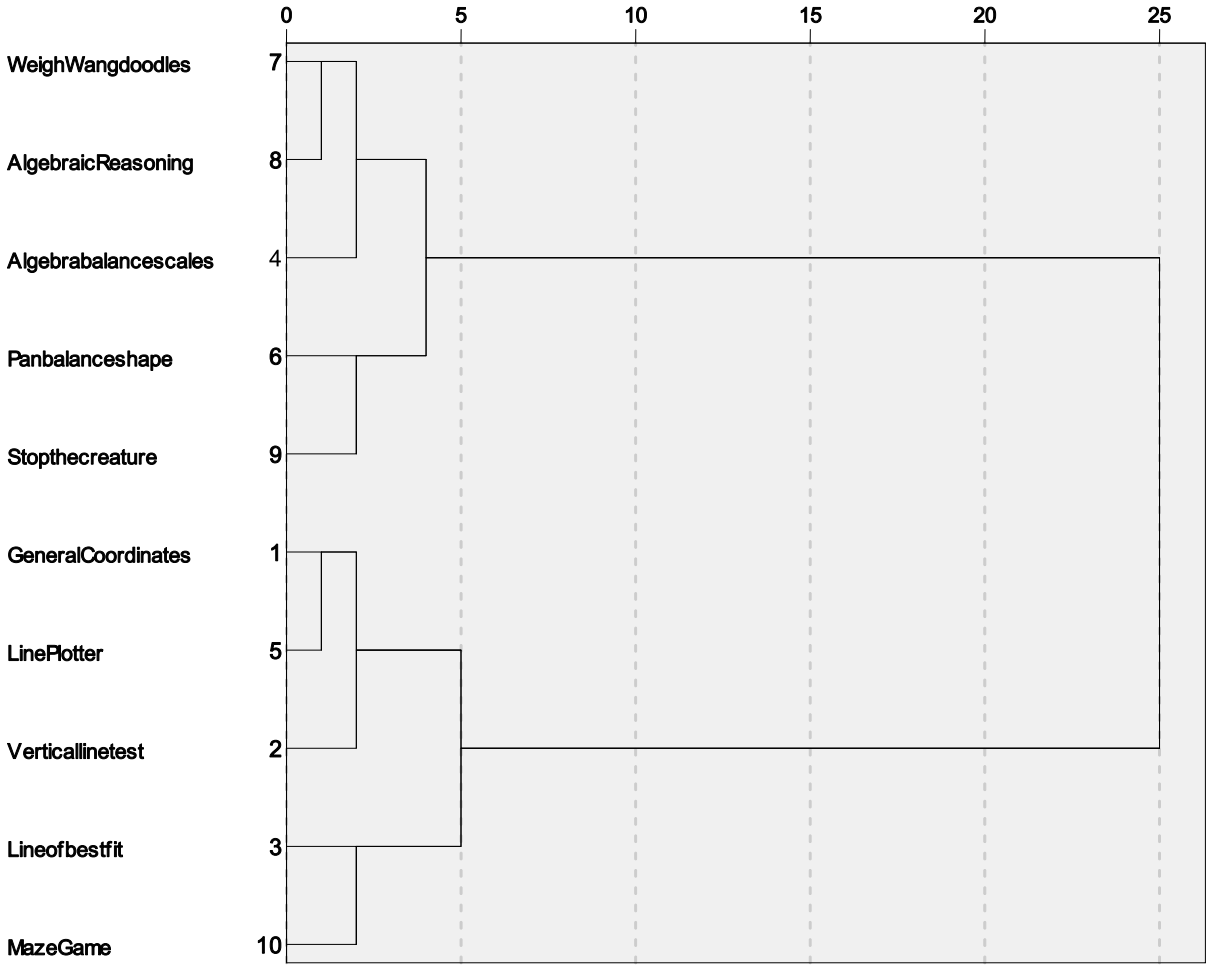

Figure 1. Dendrogram showing Euclidean distances for web-based tools in algebra.

The final stage involves interpretation. Using the dendrograms created, teachers interpret the features they discovered in relation to the tools. Undergraduate instruction in statistics may be best initiated with exploring data analysis (Cobb & Moore, 1997). While the teachers enter data and run the analysis, the primary emphasis is on the data analysis of the dendrograms. The dendrogram will show the various clusters in terms of tools; the longer the distance between constructs the less they have in common. Distinctions are modeled through multidimensional space; the more similar the constructs are the shorter the distance in space (Walker & Winter, 2007). The teachers analyze their clusters and describe why they think the clusters were broken down the way they were based on their personal ratings. In the dendrogram in Figure 1, it is clear that there are two distinct primary clusters. The clusters should now be examined to find

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patterns and relationships between the elements listed. The top cluster contains: Algebraic Reasoning, Weigh the Wangdoodles, Algebra Balance Scales, Pan Balance Shaper and Stop that Creature. All of these tools focus on numeric, algebraic reasoning, and analysis of patterns and relationships. So, this cluster might be described as *Algebraic equations and relationships*. The name or cluster description will come from the participant who describes the relationship amongst the elements that he or she perceives. The description is personal, meaning that there may be different interpretations of the cluster theme. Because the participant defined the constructs as well, both ideas (constructs and cluster themes) will be based on an individual and unique analysis. The participant should be able to justify, rationalize and explain the articulated theme. The second cluster might be described as *Coordinate grid analysis and relationships* as the contained elements relate more specifically to the coordinate grid system. Within those two clusters, there are more clusters. Examining the coordinate grid cluster, there are two other clusters shown by the Euclidian distances. The first cluster within the coordinate grid cluster contains the General Coordinates, Line Plotter, and Vertical Line Test tools. This cluster might be described as helping students understand how the coordinate system works with an emphasis on using x and y coordinates to bring about conceptual understanding of plotting points and lines. If the elements are reconsidered and explored again, a theme that focuses on examining points and lines on coordinate grids may possibly be observable. Again, the theme description is personal and should be based on the reasonable interpretation of the elements' similarities based on the perceived parallels of the elements within the cluster. The second cluster contains the Line of Best Fit and Maze Game tools. Based on the constructs described by the participant, these tools are more strategy-related, helping students use logic and reasoning to navigate through the coordinate system.

Conclusion

The framework provided in this paper is designed to integrate technology into the teaching of mathematics with the support of data analysis. Teachers are able to experience and explore web-based technology tools in mathematics and then analyze the features in relation to student learning through the use of statistical software. This experience may carry more meaning to participants than just exploring tools because it forces the teachers to critically examine how the tools support or limit learning (Blubaugh, 2009). Integrating technology in teacher education is critical to helping teachers recognize the potentials of technology-based learning in mathematics in an educational context. Technology has the potential to bring about fruitful mathematical experiences focusing on conceptual knowledge rather than just computation (Hoyles & Noss, 2009; Lin, 2010; Roschelle, Pea, Hoadley, Gordin, & Means, 2000).

The knowledge gained through the analysis of these tools may better enable the teachers to choose and employ tools that best meet their students' learning needs by understanding the mathematical uses of the tools. By analyzing the tools based on the teacher's individually perceived constructs, there is more authenticity to the cluster

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results (Fransella et al., 2004). Understanding what tools to use and when to use them is not innate; it must be learned through experience and analysis (Smith & Shotsberger, 2001). The framework provided here can be one step in the process of improving mathematics instruction with the use of technology by helping teachers discover the features of specific mathematical tools to aid in their instruction of students.

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