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The effect of inquiry-based explorations in a dynamic geometry environment on sixth grade students' achievements in polygons

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ABSTRACT

The purpose of this study was to investigate the effects of using a dynamic geometry environment (DGE) together with inquiry-based explorations on the sixth grade students' achievements in polygons and congruency and similarity of polygons. Two groups of sixth grade students were selected for this study: an experimental group composed of 66 students (34 boys and 32 girls); and a control group composed of 68 students (35 boys and 33 girls). The students in the experimental group taught with a DGE, while the students in the control group received textbook-based direct instruction. An achievement test was administered as pre-test, post-test, and delayed post-test in both groups. Qualitative data were collected through videotaped classroom observations. The results showed that the DGE together with open-ended explorations significantly improved students' performances in polygons and congruency and similarity of polygons. Furthermore, students in the experimental group showed greater interest and motivation toward learning geometry compared to those in the control group whom often showed lack of interest and curiosity. Also, students' comments and interpretations during lessons and tests were more accurate and advanced in the experimental group as they engage more in the DGE. Moreover, qualitative data suggested that boys showed greater interest in the computer-based learning environment than girls in the experimental groups although no significant gender effect on achievement was found.

1. Introduction

Geometry is one of the primary components of school mathematics. In general, school geometry is about the study of spatial objects, relationships, and transformations that have been formalized and the axiomatic mathematical systems that have been constructed to represent them (Clements & Battista, 1992). By studying geometry, students "learn about geometric shapes and structures and how to analyze their characteristics and relationships" (National Council of Teachers of Mathematics, 2000, p. 41) and develop logical thinking abilities, spatial intuition about the real world, knowledge needed to study more mathematics, and skills in the reading and interpretation of mathematical arguments (Suydam, 1985). New technological tools have emerged in the recent past as potential alternatives to traditional tools such as compass and straightedge both elementary and secondary levels. Particularly, the development of dynamic geometry environments (DGEs) for computers and calculators such as the *Geometer's Sketchpad* (Jackiw, 2001) and *Cabri géométre* or *geometry* (Laborde & Bellemain 2003) has been considered to have tremendous potential to impact teaching and learning of school geometry (Battista, 2007; Healy & Hoyles, 2001; Hölzl, 2001; Jones, 2000; Laborde, 2000; Mariotti, 2000; Sträßer, 2001). As the DGEs offer a fundamentally different learning environment than was offered by straightedge and compass (Laborde, 1998), numerous studies about DGEs have shown that DGEs ameliorated student interest and participation in geometry and positively impacted students' attitudes toward mathematics (e.g., Bielefeld, 2002; Funkhouser, 2002; Roberts & Stephens, 1999). However, despite many studies have examined students' developing understandings of geometry while using technology (for an extensive review, see Battista, 2007; Laborde, Kynigos, Hollebrands, & Strässer, 2006), how students come to understand geometry in technology-rich settings remains an open question (Arzarello, Olivero, Paola, & Robutti, 2002; Goldenberg & Cuoco, 1998).

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1.1. Purpose of the study

In his review about the development of geometric and spatial thinking, Battista (2007) points that the qualitative research results have already revealed that superior geometry learning can occur with the use of DGEs; however, quantitative research results are needed if we can generalize these results and determine whether using DGEs are "better" than using traditional paper-and-pencil methods (p. 884). Likewise, he also indicates that qualitative techniques should also be used to understand why such quantitative results are procured if an instructional strategy is found superior to other methods. Thus, the purpose of the present study was to investigate the effects of using a DGE, the *Geometer's Sketchpad* (Jackiw, 2001), in an inquiry-based learning environment on the sixth grade student's understanding of polygons and congruency and similarity of polygons compared to traditional direct instruction. More specifically, the research questions that guided the study were as follows: (1) What is the effect of using the *Geometer's Sketchpad* together with inquiry-based activities on the sixth grade student's acquisition and retention of achievement in and understanding of polygons and congruency and similarity of polygons compared to teaching with traditional direct instruction? (2) Do male and female sixth grade students differ on their acquisition and retention of achievement in and understanding of polygons and congruency and similarity of polygons? (3) Is there an interaction between gender and treatment regarding their acquisition and retention of achievement in and understanding of polygons and congruency and similarity of polygons? (4) To what extend do the computer-based activities contribute to students' better understanding of polygons and congruency and similarity of polygons, especially their prototypical thinking regarding polygons?

1.2. Students' understanding in geometry and polygons

Many studies report that student's performance in geometry is woefully lacking, and they have numerous misconceptions even in most basic concept of geometry such as the following: "an angle must have one horizontal ray", "a square is not a square if its base is not horizontal" (e.g., Battista, 2007; Clements & Battista, 1989, 1992; Fuys, Geddes, & Tischler, 1988; Hoffer, 1983). Numerous studies investigating students' concept images on polygons (e.g., Burger & Shaughnessy, 1986; Hershkowitz, 1989; Hershkowitz & Vinner, 1983; Hershkowitz, Vinner, & Bruckheimer, 1987; Hoffer, 1983; Prevost, 1985; Tsamir, Tirosh, & Stavy, 1998; Wilson, 1983) present evidence that existence of "prototypical examples" as concept images is one of the main reasons for these misconceptions. Tsamir et al. (1998) showed that thinking that the equality of the sides and the equality of the angles in any polygon are associated might induce students at various grade levels to erroneous conclusions. Through clinical interviews with the students from kindergarten to college, Burger and Shaughnessy (1986, pp. 43–45) observed the following student behaviors in response to the tasks involving polygons: Inclusion of irrelevant attributes when identifying and delineating shapes such as orientation of the figure; references to visual prototypes to characterize shapes; sorting by single attributes; inability to use properties as necessary for a shape; prohibiting class inclusions among general types of shapes. Likewise, studies by Hershkowitz and Vinner (1983) and Hershkowitz et al. (1987) suggest that each basic geometrical concept has one or more prototypical examples and these are accomplished first. Therefore, they exist in the concept image of most students and teachers. Similarly, in exploring the relationships between children's definitions of rectangles and their choice of examples, Wilson (1983) found that the students' choice of examples was based more on their own prototypes instead of their own definitions. Such prototypical judgments were also demonstrated by other studies (e.g., Hershkowitz, 1989; Hoffer, 1983; Prevost, 1985). Hoffer (1983) reported that students often could not identify a right-angled trapezoid as a trapezoid if it does not look like a prototypical trapezoid. Prevost (1985) found that most of the seventh and eighth grade junior high school students were unable to identify common figures such as rectangles, squares, and trapezoids even though all the students could *parrot* the definitions they had learned at school. Furthermore, Hershkowitz (1989) found that students do not consider a square as a quadrilateral because it has four equal sides while other quadrilaterals do not.

1.3. Technology in teaching and learning of geometry

Various software environments such as the *Logo-based Turtle Geometry* (Abelson & diSessa, 1981), *Cabri-Géomètre* (Laborde & Bellemain 2003), and *Geometer's Sketchpad* (Jackiw, 2001) are designed to assist the teaching of school geometry. Particularly, DGEs are used successfully the teaching and learning of geometry as they allow direct manipulation of geometric objects (Christou, Jones, Mousoulides, & Pittalis, 2006; Laborde et al., 2006). One of the restrictions of DGEs using with young children is that they often require basic knowledge of geometric constructions for most common geometric figures. This is an important requirement for students to make the transition from drawing to construction when they first encounter DGEs (Finzer & Bennet, 1995). However, this transition can be difficult for young children since it requires knowledge of geometric properties and relations to construct (Olive, 1998). Hence, ready-made shapes that could be manipulated without having to construct them first are often used with young children (e.g., see Battista, 1998).

It is suggested that DGEs can support higher order thinking skills like generalization (e.g., Knuth & Hartman, 2005; Vincent, 2005; Zheng, 2002). For example, middle school students can advance from the first van Hiele level (i.e., visual) to the second and third levels (i.e., descriptive/analytic and abstract/relational) while using the environments to construct figures with certain properties (Pratt & Ainley, 1996; Vincent & McGrae, 1999). Moreover, working with pre-constructed figures, students can deepen their understanding of geometric shapes and figures (Battista, 1998; Olive, 1991). Dixon (1997) showed that DGEs could facilitate middle school students' learning of transformation geometry concepts. Various studies (e.g., see Glass, 2001; Sinclair & Crespo, 2006) have provided evidence that the dynamic nature of the environment can influence the development of students' understandings. According to Hollebrands (2007), student-directed inquiry in DGEs is possible with structured instruction that guides students to the point at which they can make and test conjectures. It is important to design student-centered learning environments where students can work collaboratively to formulate theories and delineate their own conclusions (Cognition and Technology Group at Vanderbilt, 1992).

Research studies using DGEs are generally case studies and are more qualitative than quantitative in nature. Many of these case studies have largely provided evidence supporting the general claim on the role of DGEs in improving teaching and learning of geometry by supporting processes of exploration (Clements & Battista 1994; Hollebrands 2002) and conjecturing (Hollebrands, 2002; Olivero & Robutti, 2007; Vincent & McCrae 1999). Further, given their capacity to test multiple cases, DGEs help students to generalize leading to their development toward a geometric proof (Christou, Mousoulides, Pittalis, & Pitta-Pantazi, 2004; Hadas, Hershkowitz, & Schwarz, 2000; Leung