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IJIER 1142 No. of Pages 21

ARTICLE IN PRESS

International Journal of Educational Research xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Educational Research

journal homepage: www.elsevier.com/locate/ijedures

Geometry interventions for K-12 students with and without disabilities: A research synthesis

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ARTICLE INFO

Article history:
Received 3 February 2016
Accepted 8 April 2016
Available online xxx

Keywords:
Geometry
Intervention
Review
Disabilities

ABSTRACT

Geometry instruction is an important yet often overlooked subject in current education research and practice. This study synthesized intervention studies focusing on instruction to improve geometry skills for K-12 students with and without disabilities. Thirty two studies met the inclusion criteria: being published in English-language peer-reviewed journals or dissertations between 1980 and 2015, using quantitative method, and targeting kindergarten through twelfth grade students in the United States. Five studies examined the effectiveness of new geometry curricula, sixteen studies investigated instructional strategies, and eleven studies explored educational technologies. Although a broad range of geometric subjects were covered for normal achieving students, most of the studies for students with special needs primarily focused on very basic geometry skills. Only one study was found about teaching geometry to kindergarteners. Limitations and directions for future research are discussed.

1. Introduction

Geometry is a critical subject of mathematics education that involves the properties and relationships of points, lines, shapes, and space. Unfortunately, geometry instruction is an ongoing challenge for K-12 teachers in the United States. Markedly low achievement in geometry has characterized American students on both national and international assessments over the past two decades. Most tasks involving geometric problem solving on the 2013 National Assessment of Educational Progress (NAEP) did not show significant student performance gains (NAEP report card) (National Assessment of Educational Progress Report Card, 2013). Trends in International Mathematics and Science Study [TIMSS] (2011), reported similar findings in an international comparison study. Among the four mathematics content areas (i.e., algebra, number, data and chance, and geometry) that were assessed in the TIMSS (2011), geometry was the weakest area of proficiency for U.S. eighth-graders (Provasnik et al., 2012). Although TIMSS reported significant improvement in U.S. eighth-graders' algebra performance between 1999 and 2003, significant improvement was not found in their geometry performance during this time (Gonzales et al., 2004).

Geometry has become an increasingly difficult mathematics concept for students as they reach the high school years, with difficulties in this area beginning in the early education years (Dobbins, Gagnon, & Ulrich, 2014). Reflecting the increasing concerns on students' geometry learning, the K-12 Common Core State Standards in Mathematics (Common Core States Standards, 2011) and National Council of Teachers of Mathematics (National Council of Teachers of Mathematics Principles & Standards for School Mathematics, 2000) have provided a set of guidelines for instructional standards with an

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http://dx.doi.org/10.1016/j.ijer.2016.04.004
0883-0355/

Please cite this article in press as: C. Bergstrom, D. Zhang, Geometry interventions for K-12 students with and without disabilities: A research synthesis, International Journal of Educational Research (2016), http://dx.doi.org/10.1016/j.ijer.2016.04.004

increased emphasis on geometry instruction at all levels. According to NCTM (2000), standards for geometry learning and instruction have moved from an emphasis on rote learning to problem solving. Common Core States Standards (2011) has significantly increased the percentage of geometric topics and deepened the requirements in order to take students from superficial "knowing" to "understanding" the depth of the required mathematical concepts (Porter, McMaken, Hwang, & Yang, 2011). Specifically, shape identification and reasoning about shape attributes seem to be the focus of geometry learning from kindergarten to middle grades elementary education in CCSSM. Real-world problem solving becomes a major focus for the upper grades in elementary education and middle schoolers. Sixth graders focus on solving problems involving volume, area, and surface area. By the seventh grade, students begin drawing, constructing, and describing geometric figures and the relationships between them; and eighth graders should learn congruency and the similarity of geometric models, as well as the Pythagorean theorem. When students approach high school, the geometry standards become more complex and in depth. High school students are expected to develop an understanding of the attributes and relationships of geometric objects and apply this knowledge in diverse contexts. Students are taught skills in multiple areas including right triangles, circles, areas of congruence, trigonometry, geometric measurement, modeling with geometry, and expressing geometric properties with equations. In all grade levels students should learn in geometry environments that have appropriate tools that allow them to develop a strong understanding and explore geometric occurrences in the real world. However, it is unclear to what extent the existing interventions align with CCSSM and NCTM.

1.1. Geometry curriculum, instructional strategies, and technologies

Geometry is often an overlooked subject. Compared to the rich literature on numerical instruction, research investigating students' development of geometric thinking is rather limited. The inadequate treatment of geometry in traditional mathematics education has been under criticism (Clements & Sarama, 2011). Some researchers attribute students' poor performance to the traditional geometry curriculum, which focuses on "recognizing and naming geometric shapes and learning to write the proper symbolism for simple geometric concepts" (Clements & Battista, 1986). In contrast, these researchers believe "that elementary geometry should be the study of objects, motions, and relationships in a spatial environment" (Clements & Battista, 1986; p. 11). Concerns about geometry curriculum also come from international comparison research, which has concluded that mathematics education in the United States should become substantially more focused, rigorous, and coherent to improve mathematics achievement of students in America (Ma, 1999; Schmidt, Wang, & McKnight, 2005). Additionally, a traditional curriculum places emphasis on axiomatic systems and includes a considerable amount of proof. Contrary, some believe that we should abandon proof for a less formal investigation of geometric ideas (Battista & Clements, 1995). It is critical to examine whether there is any improved or reform based geometry curricula available and how effective they are. In this comprehensive review we aimed to identify and summarize the characteristics of existing new geometry curricula and evaluate their effectiveness.

In addition to the curriculum issue, we aimed to examine the effects of instructional strategies employed in enhancing students' geometry learning. Previous literature on varying instructional strategies, such as representation techniques (Goldin, 2002), problem-based learning (Hmelo-Silver, 2004), peer tutoring, collaborative learning (O'Donnell, 1999), and so forth, have been documented to be effective for learning mathematics and science in a rich body of research. However, a search in What Works Clearinghouse, a resource with authority to evaluate the evidence for school intervention programs (What Works Clearinghouse, 2015), yielded no recommended interventions for teaching geometry. Given the unique characteristics (e.g., spatial based) of geometry learning it is critical to describe instructional strategies that are effective for learning geometry. In comparison to the intervention strategies for teaching numerical mathematics subjects, there has been sparse research on intervention strategies for teaching geometry. Additionally, there was no existing research synthesis systematically evaluating the efficacy of different types of interventions.

Due to the visual spatial characteristics of geometry learning instruction, there has been extensive research on representing geometric figures with technologies. Research about the effectiveness of educational technologies has yielded mixed results: Proponents of educational technologies claimed that technology is beneficial when used as multiple means of representations to accommodate diverse learners, and to facilitate a collaborative community (Cheung & Slavin, 2012). In contrast, opponents of educational technologies suggested the drawbacks of abusing them. For example, a meta-analysis (Zhang & Xin, 2012) indicated that assistive technology was less effective than other human-delivered interventions for students with difficulties in mathematics. There is also research showing that different types of educational technologies generate different levels of effectiveness (Cheung & Slavin, 2013). Providing pictorial presentations are particularly important for learning geometry. It is plausible that technologies positively affect students' learning outcomes. However, evidence of most technologies for teaching and learning geometry on the current education market has been rigorously evaluated. Consequently, the effective application and the scaling-up of educational technologies are thwarted. The present synthesis aimed to review the mechanism and effectiveness of technologies that promote the understanding of how technology works to enhance student learning in geometry.

1.2. Individual differences in geometry interventions

Individual differences are also of interest in the present research. For students of different abilities, differentiated instruction methods and curricula may be needed. For example, it is not uncommon that special education students receive

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