Contemporary Educational Psychology 41 (2015) 198–208

Contents lists available at ScienceDirect

Contemporary Educational Psychology

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

Student, teacher, and instructional characteristics related to students' gains in flexibility

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ARTICLE INFO

Article history:
Available online 6 March 2015

Keywords:
Flexibility
Algebra
Discussion questions
Teacher characteristics
Student characteristics

ABSTRACT

Flexibility in problem solving has been widely recognized as an important skill for students' mastery of mathematics. Here we utilize the Opportunity-Propensity framework to investigate student characteristics, teacher characteristics, and teacher instructional practices that may be associated with students' gains in flexibility in algebra. Teacher and student data were collected from 8th and 9th grade Algebra I teachers in Massachusetts as part of a larger study on the impact of a researcher-developed year-long supplementary curriculum that focused on improving students' flexibility. We explore student demographics, teacher background characteristics and teacher instructional practices as predictors of student gains in flexibility. We further investigate instructional practices associated with flexibility gains through an analysis of teacher questioning in the classroom for teachers whose students achieved the greatest gains in flexibility and those whose students achieved the least gains. Our results indicate that prior knowledge is a reliable predictor of flexibility gains and that gender is an important student background characteristic associated with the development of flexibility. In addition, although high and low gain teachers did not differ in their implementation fidelity, high flexibility gain teachers asked more *open-ended* questions that prompted students to verbalize the main ideas of the lesson.

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1. Introduction

Flexibility in mathematics problem solving, which is typically defined as the ability to generate, use and evaluate multiple solution methods for given problems, has been identified as an important competency for mathematics learners in recent policy documents throughout the world (Australian Education Ministers, 2006; Brophy, 1999; Common Core State Standards Initiative, 2010; Kultusministerkonferenz, 2004; National Council of Teachers of Mathematics, 2006; National Mathematics Advisory Panel, 2008; National Research Council, 2001; Singapore Ministry of Education, 2006; Treffers, 1991; Woodward et al., 2012). As noted by Silver and colleagues, "It is nearly axiomatic among those interested in mathematical problem solving as a key aspect of school mathematics that students should have experiences in which they solve problems in more than one way" (Silver, Ghousseini, Gosen, Charalambous, & Strawhun, 2005, p. 288). As a result, a growing literature has examined the development of flexibility of school-aged learners (e.g., Beishuizen, van Putten, & van Mulken, 1997; Blöte, Van der Burg, & Klein, 2001; Dowker, Flood, Griffiths, Harriss, & Hook, 1996; Lynch & Star, 2014; Newton, Star, & Lynch, 2010; Star & Rittle-Johnson, 2008; Star & Seifert, 2006). This work has primarily focused on understanding the relationships between flexibility and conceptual and procedural knowledge, measuring flexibility, and understanding instructional conditions that foster the development of flexibility (e.g., comparing two ways to solve a problem). Less is known, however, about factors that contribute to flexible knowledge development in students, such as student characteristics, teacher characteristics and specific instructional practices.

Although it is yet unclear what contributes to the development of *flexibility*, research suggests that student *achievement* in mathematics is predicted by a variety of factors. Explaining variance in achievement has been a primary goal of research based on the opportunity-propensity framework (e.g., Byrnes & Miller, 2007; Byrnes & Wasik, 2009; Jones & Byrnes, 2006). According to this framework, students must have *opportunity* to learn, but they also must have the *propensity* to take advantage of the opportunity. In addition, some background factors can exert both a direct and an

An earlier version of this paper was presented at the symposium, "Strategy Change in Mathematics: The Impact of Personal Characteristics and Learning Opportunities" at the 2013 European Association of Research on Learning and Instruction (EARLI) Biennial Conference, Munich, Germany.

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http://dx.doi.org/10.1016/j.cedpsych.2015.03.001
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indirect influence on achievement (Byrnes & Miller, 2007). The present study seeks to extend this work by exploring background, opportunity, and propensity factors related to the development of flexibility. In particular, we investigated student and teacher characteristics and instructional practices that may be associated with students' gains in flexibility in algebra.

1.1. Problem-solving flexibility in mathematics

Building students' conceptual knowledge of mathematics continues to be a high priority in mathematics education (e.g., National Council of Teachers of Mathematics, 2006). Yet in recent years, there is a growing awareness that procedural knowledge should also play a key role in desired learning goals for students (National Research Council, 2001; Star, 2005). Many mathematics educators and researchers now consider procedural fluency, defined as "knowledge of procedures, knowledge of when and how to use them appropriately, and skill in performing them flexibly, accurately, and efficiently" (National Research Council, 2001, p. 121), to be a core component of mathematical proficiency.

In particular, the construct of *problem solving flexibility* (or simply, *flexibility*) is gaining traction as a way to describe productive outcomes associated with knowing and using mathematical procedures (e.g., Berk, Taber, Gorowara, & Poetzl, 2009; Blöte et al., 2001; Heirdsfield & Cooper, 2002; Rittle-Johnson & Star, 2007; Rittle-Johnson, Star, & Durkin, 2012; Star, 2005, 2007; Star & Seifert, 2006; Verschaffel, Luwel, Torbeyns, & Van Dooren, 2007). Star and colleagues define flexibility as the ability to solve mathematics problems in multiple ways and know when it is most appropriate to apply particular solution methods for a given problem (Star, 2005, 2007; Star & Rittle-Johnson, 2008; Star & Seifert, 2006). Star's conceptualization of flexibility is closely related to adaptive expertise (Hatano, 2003; Hatano & Inagaki, 1986), which is defined as the ability to execute meaningfully learned procedures creatively and flexibly. For example, the problem $3(x+1) = 18$ can be solved by distributing 3 on the left side first or by dividing by 3 on both sides first. A student with flexible knowledge in equation solving would know when it might be advantageous to divide as a first step (e.g., when the coefficient divides the product evenly). Prior studies have found that flexibility can be reliably assessed and is distinct from, but related to, conceptual knowledge (Schneider, Rittle-Johnson, & Star, 2011). In addition, gains in flexibility have been linked to improvements in students' conceptual and procedural knowledge (Rittle-Johnson & Star, 2009; Rittle-Johnson, Star, & Durkin, 2009; Star & Rittle-Johnson, 2009).

The existing research base on flexibility has highlighted instructional conditions that lead to improved flexibility. Rittle-Johnson and colleagues have shown that providing students with opportunities to compare multiple methods for solving mathematics problems leads to greater flexibility (e.g., Rittle-Johnson & Star, 2007, 2011; see Alfieri, Nokes-Malach, & Schunn, 2013 for a review). However, generally absent from this literature on flexibility are studies of the development of flexibility in authentic classroom environments. Prior studies by Rittle-Johnson and Star (2009) and colleagues were very short in duration (usually one week long), often replaced classroom teachers with research assistants who followed instructional scripts, and relied on self-paced written curriculum worksheets that students worked through in pairs without the aid of a teacher. How teachers can provide instruction that facilitates the development of flexibility within the dynamic and complex environment of real classrooms is largely unexplored. For example, can the scripted instructional practices and partner-completed self-paced worksheets used in prior studies for promoting flexibility be adapted for successful use in whole class instruction in actual classrooms? If so, what types of challenges, both in terms of content knowledge and pedagogy, do teachers face in teaching for improved flexibility? To what extent do prior results about the role of prior knowledge in the development of flexibility hold true in real classroom environments? Questions such as these are largely unanswered at present but are critically important, particularly as teachers continue to receive recommendations from policy reports advocating a focus on flexibility (e.g., Woodward et al., 2012).

1.2. The opportunity-propensity framework

As noted above, the opportunity-propensity framework (e.g., Byrnes & Miller, 2007; Byrnes & Wasik, 2009; Jones & Byrnes, 2006) serves as the theoretical basis for our examination of the development of flexibility. Below we explore background factors, opportunity factors, and propensity factors that have been found to explain variance in students' achievement in mathematics, with particular attention to which of these factors might also be critical in understanding the development of flexibility.

1.2.1. Background factors

Within studies of student achievement in mathematics, socioeconomic status (SES) has persisted as a predictor of achievement even when other important factors are controlled for (Byrnes & Miller, 2007; Perie, Moran, & Lutkus, 2005). SES, along with other background factors such as parental aspirations, gender and ethnicity, have the potential to impact students' opportunities to learn mathematics (Byrnes & Wasik, 2009). For example, students from higher socio-economic status (SES) families may have access to increased opportunities, which in turn may lead to higher achievement. Because these factors occur earlier in time and can impact opportunities to learn, Byrnes and colleagues sometimes refer to them as *antecedent* factors.

1.2.2. Opportunity factors

An *opportunity* to learn mathematics can be informal (e.g., playing a game at home) or formal, and it can vary in both quality and quantity. For example, opportunities to take rigorous as opposed to general mathematics courses contribute to achievement (Byrnes & Miller, 2007), but teacher qualifications may make a difference in the quality of such opportunities. In particular, teacher qualifications such as years of experience and subject-specific training are thought to be generally important for student achievement in mathematics (e.g., Goldhaber & Brewer, 1997), yet how these characteristics are related to the development of flexibility is unknown. Strong mathematics content knowledge is also important, although it is unclear whether a full major in mathematics is critical (Wilson, Floden, & Ferrini-Mundy, 2001). What may be more critical is teachers' mathematical content knowledge that is specific to the classroom (e.g., knowledge of how to represent mathematical ideas, knowledge of alternate solution methods). Hill, Rowan, and Ball (2005) found that this kind of mathematical knowledge for teaching was related to achievement gains in early elementary school. It is unclear how either type of mathematical knowledge is related to more nuanced outcomes, such as students' ability to flexibly solve algebra problems.

In addition to teacher qualifications, teaching practices may play a role in the development of flexibility. When using new instructional materials, teaching practices can differ even among teachers with similar levels of fidelity (Taylor & Star, 2011). For example, some teachers may provide more opportunity than others for student talk. Researchers agree that student talk is beneficial for learning mathematics, particularly when students are providing clear explanations of their ideas (Franke et al., 2009; Walshaw & Anthony, 2008).

In order to elicit this kind of student talk, teacher questioning is critically important (Sahin & Kulm, 2008). Researchers exploring teachers' use of questioning in the mathematics classroom have adopted a variety of frameworks to capture both high and low levels of questions. Two recent studies highlighted probing questions as

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