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Quality of geometry instruction and its short-term impact on students' understanding of the Pythagorean Theorem

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Abstract

This article presents findings from a German–Swiss video-based classroom study. The research examines how three basic dimensions of instructional quality impact the development of students' understanding of the Pythagorean Theorem. The study sample comprised 19 German and 19 Swiss mathematics classes. A three-lesson introductory unit on the Pythagorean Theorem was videotaped in all classes. Multilevel analyses revealed both classroom management and cognitive activation to have positive effects on mathematics achievement. The results also provide empirical evidence that cognitive activation and a supportive climate moderate the relationship between mathematics-related interest and mathematics achievement.
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1. Introduction

This article draws on data from a video study to examine the impact of three basic dimensions of instructional quality on students' mathematics achievement. In contrast to previous video studies (Hiebert et al., 2003) that examined lessons in different mathematical content areas, we standardised the content area of the lessons videotaped, and recorded a three-lesson introductory unit on the Pythagorean Theorem in 38 German and Swiss classes. We expected this content standardisation to provide more differentiated insights into how the quality of the learning environment impacts students' achievement in mathematics. The analyses presented in this article are part of the binational study "Quality of instruction, learning and mathematical understanding" (Hugener et al., 2009; Klieme & Reusser, 2003).

1.1. Instruction and school achievement

Quantity and quality of instruction are important components in models and frameworks of school effectiveness. In their influential analysis of extant empirical evidence, Wang, Haertel, and Walberg (1993) demonstrated that the effects of classroom management and quality of student–teacher interaction (especially the intensity and quality of questions and answers) are about as strong as the effects of cognitive and metacognitive abilities and family background. Moreover, recent studies emphasise that, relative to other determinants of the academic learning process, the impact of both teacher characteristics and instruction is stronger than had previously been assumed (Babu & Mendro, 2003; Lanahan, McGrath, McLaughlin, Burian-Fitzgerald, & Salganik, 2005; Scheerens & Bosker, 1997; Wayne & Youngs, 2003).

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The above findings raise the question of which features of instruction are associated with stronger gains in student achievement. Although previous meta-analyses and process-product studies have produced comprehensive overviews of features of effective instruction, these lists can only be considered the first steps towards a systematic theoretical conceptualisation (Fraser, Walberg, Welch, & Hattie, 1987; Scheerens & Bosker, 1997; Wang et al., 1993). Theoretical and conceptual frameworks developed in recent years provide useful structures for the interpretation and elucidation of empirical findings on how different instructional approaches influence learning processes and learning outcomes (Bolhuis, 2003; De Corte, 2004; Greeno, 2006; Hiebert & Grouws, 2007; Seidel & Shavelson, 2007). All of these frameworks emphasise the importance of students' cognitive engagement.

1.2. Models of learning opportunities and uses of instruction

Recent approaches to instructional research based on constructivist perspectives do not regard learning as an information-processing activity guided by the teacher, but as an individual, self-directed and cumulative process (De Corte, 2004). This idea is reflected in complex models incorporating multiple goals, both cognitive and motivational, that focus on the learning activity of students in terms of their active construction of knowledge and acquisition of skills (Kunter, 2005; Pauli & Reusser, 2006). In the research on classroom teaching, these ideas are often connected within the concept of learning opportunities and uses of instruction that was introduced by Fend (1981) and elaborated by Helmke (2003) as a design for research on teacher effectiveness. The underlying idea is that learning processes cannot be controlled from the outside; rather, the teacher provides learning opportunities that must be perceived and utilised by the student to be effective. Researchers in mathematics education also regard the "opportunities to learn" as a key condition for student achievement. Teachers' allocation of classroom time to particular contents, the learning goals and expectations they set, and the fit between learning content and goals, on the one hand, and students' knowledge, on the other, all influence the opportunities that students have to learn (Hiebert & Grouws, 2007).

However, this conception of instruction is not specific enough to describe the interaction between student learning characteristics and students' uses of learning opportunities, or to predict which instructional features are used and how, and to what effect (Hiebert & Grouws, 2007). Moreover, instruction often varies as a function of knowledge domain or even of the context and skills to be learnt by students (Brophy, 2001; Campbell, Kyriakidis, Muijs, & Robinson 2004; De Corte, 2004; Seidel & Shavelson, 2007). More specific pedagogical–psychological theories and ideas about the teaching of mathematics are required. With respect to the promotion of conceptual understanding, which is of particular interest in this article, researchers from various backgrounds have developed approaches stressing the importance of demanding cognitive activities that prompt students to engage with the learning content (Hiebert & Grouws, 2007; Mayer, 2004; Reusser, 2006).

1.3. Basic dimensions of instructional quality

Various attempts have been made to specify features of mathematics instruction that are likely to offer more opportunities to learn and to promote a deeper conceptual understanding of mathematical topics. Klieme, Lipowsky, Rakoczy, and Ratzka (2006) and Kunter et al. (2007) have identified three basic dimensions of instructional quality that link teaching and students' learning outcomes in mathematics classrooms: cognitive activation, supportive climate, and classroom management. We outline these three basic dimensions below, first describing the instructional features that characterise them, and then relating them to constructs from domain-specific approaches to instruction and presenting empirical evidence concerning their effects.

1.3.1. Cognitive activation

Researchers from various backgrounds have drawn similar conclusions with respect to mathematics instruction: Mathematics instruction that promotes conceptual understanding attends explicitly to concepts and specifies the connections among mathematical facts, procedures, ideas, and representations (Hiebert & Grouws, 2007). Conceptual instruction encourages students to discover and understand the meaning underlying procedures, to discuss the relationships between concepts, to compare different solution strategies, and to solve non-routine problems (Brophy, 2000). New concepts are introduced by building on students' ideas, experiences, and prior knowledge (Greeno, 2006; Reusser, 2006).

Another key feature of mathematical instruction promoting conceptual understanding is the cognitive level of students' activities. Mathematical tasks and problems that make higher cognitive demands on students—or, more generally, mathematical instruction that prompts high levels of cognitive functioning and processing—are regarded as a prerequisite for conceptual understanding (Brown, 1994; Greeno, 2006; Hiebert & Grouws, 2007; Hiebert & Wearne, 1993; Mayer, 2004; Stein & Lane, 1996).

The quality of interaction and participation in classrooms is another important factor (Greeno, 2006). According to Brophy (2000, p. 19) "effective teachers…use questions to stimulate students to process and reflect on content, recognize relationships among and implications of its key ideas, think critically about it, and use it in problem solving, decision making or other higher-order applications. The discourse is not limited to rapidly paced recitation that elicits short answers to miscellaneous questions. Instead, it features sustained and thoughtful development of key ideas. Through participation in such discourse, students construct and communicate content-related understandings". Grouws and Cebulla (2000) stress the importance of conflict and contradiction during whole-class discussion for students' conceptual understanding.

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