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Teachers' content and pedagogical content knowledge on rational numbers: A comparison of prospective elementary and lower secondary school teachers

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HIGHLIGHTS

- Prospective teachers have limited CK and PCK on rational numbers.
- Teachers' CK and PCK are significantly positively related.
- CK is a necessary, but not sufficient condition for PCK.
- Prospective secondary teachers outperform prospective elementary teachers on CK.
- No significant difference in PCK is observed between both groups of teachers.

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ABSTRACT

Rational numbers are amongst the most difficult topics in the elementary and secondary school curriculum and teaching them requires an appropriate knowledge base of teachers to properly deal with students' difficulties. We investigated prospective teachers' content knowledge (CK) and pedagogical content knowledge (PCK) on rational numbers, the relationship between CK and PCK, and differences in CK and PCK among prospective elementary teachers (trained as general classroom teachers) and lower secondary teachers (trained as subject-specific classroom teachers). The results revealed gaps in prospective teachers' CK and PCK, a positive correlation between CK and PCK, and a better CK but not PCK for secondary compared to elementary school teachers.

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1. Introduction

Research in many countries provides evidence of elementary and secondary students' limited understanding in the rational number domain (e.g., Mack, 1990; Zhou, Peverly, & Xin, 2006). To effectively deal with students' difficulties, (prospective) teachers should have appropriate content knowledge (CK) (i.e., conceptual and procedural knowledge about the rational number domain), as well as pedagogical content knowledge (PCK) (i.e., knowledge of students' misconceptions and buggy procedures about rational numbers and of multiple representations to prevent and/or remedy these misconceptions and buggy procedures) (Shulman, 1986). There is some research evidence that (prospective) teachers lack CK and PCK in the domain of rational numbers (e.g., Ball, 1990; Tirosh, 2000; Turnuklu & Yesildere, 2007), but their actual nature has not yet been systematically studied. The same holds true for the relationship between prospective teachers' CK and PCK in the rational number domain. The aim of our study is threefold. First, it aims at documenting shortcomings in prospective teachers' CK and PCK regarding rational numbers. Second, the study intends to address the relationship between prospective teachers' CK and PCK. A third

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goal is to compare the CK and PCK of prospective elementary teachers (grades 1–6, trained as general classroom teachers) and lower secondary teachers (grades 9–12, trained as specialized mathematics teachers).

After presenting an overview of the existing research on (prospective) teachers' CK and PCK in mathematics in general, and rational numbers in particular, we explain our research methods, followed by the main findings. In the conclusion we sum up our key findings and discuss their theoretical and practical implications.

2. Theoretical framework

2.1. Teachers' content and pedagogical content knowledge in mathematics

Teachers' competencies play a key role in student achievement (Hattie, 2009). Blömeke, Felbrich, Müller, Kaiser, and Lehmann (2008, p. 720) refer to professional competence to label that "what teachers need to act successfully during their professional life". A crucial component of that competence is their professional knowledge. In his seminal work in conceptualizing teachers' professional knowledge, Shulman (1987) distinguished between seven categories in teachers' knowledge base. Especially the categories *content knowledge* (CK) and *pedagogical content knowledge* (PCK) have been taken on in empirical research on teachers' competence and its relationship to students' learning outcomes (Kleickmann et al., 2013). CK refers to the amount and the organization of teachers' knowledge of the subject matter (Shulman, 1986). It involves conceptual knowledge (i.e., knowledge of the concepts, including principles and definitions) as well as procedural knowledge (i.e., knowledge of procedures, including action sequences and algorithms used in problem solving) (Star, 2005). PCK refers to knowledge of the subject matter for the purpose of teaching. Shulman (1986) identified two central components in PCK, namely (1) knowledge of instructional strategies and representations, and (2) knowledge of students' misconceptions. Shulman's work has been very influential in research on teaching and teacher education, mainly in science and mathematics education (Depaepe, Verschaffel, & Kelchtermans, 2013). In mathematics education, three large-scale studies have established the empirical research base on teachers' CK and PCK and their relationship to teachers' instructional behavior and students' learning outcomes, namely (1) the MKT study (Mathematical Knowledge for Teaching), (2) the COACTIV study (professional competence of teachers, COgnitively ACTIVating instruction, and development of students' mathematical literacy), and (3) the TEDS-M study (Teacher Education and Development Study in Mathematics).

Ball, Hill, and colleagues (e.g., Ball, Thames, & Phelps, 2008; Hill, Rowan, & Ball, 2005) investigated teachers' mathematical knowledge for teaching (MKT) and its impact on their instructional quality and student achievement. MKT covers three categories related to CK: common content knowledge, specialized content knowledge, and horizon content knowledge. Another set of three categories within MKT concerns PCK: knowledge of content and students, of content and teaching, and of content and curriculum (Ball et al., 2008). Hill and colleagues (Hill et al., 2005) developed a test to measure teachers' MKT on three domains: (1) number concepts, (2) operations, and (3) patterns, functions, and algebra. The test focuses however not on PCK but on two categories that were distinguished in CK, i.e. common content knowledge (mathematical knowledge and skills used in settings other than teaching) and specialized content knowledge (mathematical knowledge and skills unique to teaching mathematics). Data revealed that students' learning gains for mathematics in first and third grade were significantly related to teachers' knowledge as measured by the MKT-test, even after controlling for student background variables (e.g., SES, gender) and teacher-level variables (e.g., years of experience, instructional methods) (Hill et al., 2005). This study provided empirical evidence that teachers' CK is an important predictor of students' mathematics achievement.

The COACTIV study (e.g., Baumert et al., 2010; Kleickmann et al., 2013; Krauss et al., 2008) investigated not only the impact of teachers' CK, but also of their PCK, on students' mathematics achievement. A test was constructed for measuring mathematics teachers' CK and PCK about arithmetic, algebra, geometry, functions, and probability. In addition to Shulman's components of PCK (i.e., knowledge of instructional strategies and representations, and knowledge of students' misconceptions) a third component was distinguished: knowledge of multiple solution paths to a particular mathematical task. Krauss et al. (2008) investigated whether CK and PCK could be distinguished empirically, and, second, whether the depth of mathematics training of secondary school teachers impacted the level of the CK and PCK. The results revealed that CK and PCK were empirically distinctive constructs, although they were significantly positively related. In addition, it was observed that experienced teachers who had received more training in mathematics outperformed their colleagues with less mathematics training on CK and PCK. The difference between both groups, however, was smaller for PCK than for CK. Similar results were obtained by Kleickmann et al. (2013) who compared the CK and PCK of four different teacher populations – prospective teachers at the beginning of their training, prospective teachers at the end of their training, teachers in their practical induction phase, and in-service teachers – who either were enrolled in an academic (of 9 semesters, with a main focus on CK) or a non-academic track (of 7 semesters, with a main focus on PCK and general pedagogy). The CK of pre- and in-service teachers (as well as the growth of CK from pre-to in-service teachers) was found to be significantly higher for those following the academic track than those following the non-academic track. The same holds true for the PCK of academic and non-academic trained in-service teachers, although during teacher training no significant difference in PCK was observed between the academic and non-academic track. Baumert et al. (2010) investigated the relationship between in-service teachers' CK and PCK, on the one hand, and their instructional quality and student learning gains, on the other hand. Teachers' instructional quality was measured through a student questionnaire, while students' learning gains were measured through a pre- and posttest covering the standard content of grade 10 mathematics. Both CK and PCK were found to make a unique contribution to teachers' instructional quality and student learning gains, with the impact of PCK being larger. The authors, thus, concluded that PCK can only be obtained at the condition of one having mastered a substantial level of CK, but that CK alone is insufficient for the acquisition of PCK.

In the TEDS-M study (e.g., Blömeke & Kaiser, 2012; Senk et al., 2012) a CK and PCK test was developed covering four mathematics subdomains: (1) number and operations, (2) algebra and functions, (3) geometry and measurement, and (4) data and chance. PCK was operationalized in terms of three components: mathematical curricular knowledge (e.g., knowing the school mathematics curriculum, establishing appropriate learning goals), knowledge of planning for mathematics teaching and learning (e.g., predicting typical students' responses, planning appropriate methods for representing mathematical ideas), and enacting mathematics for teaching and learning (e.g., explaining or representing mathematical concepts or procedures, diagnosing students' responses). Based on the TEDS-M data, Senk et al. (2012) investigated the level and depth of prospective teachers' CK and PCK, and how it varied across teacher training programs (i.e., lower primary generalists, primary generalists, primary and lower secondary

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