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ELEMENTARY TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE AND STUDENT ACHIEVEMENT IN SCIENCE EDUCATION

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Abstract: The scope of this paper is to explore whether elementary science teachers' pedagogical content knowledge (PCK) in the content area "states of matter and changes of state" contributes to gains in elementary students' understanding of related concepts. The paper reports on a value-added study with a sample of 60 fourth-grade classrooms and their science teachers. The data derived from a project funded by the German Research Foundation (project "PLUS"). Teachers' PCK and student achievement concerning the mentioned scientific topic were directly assessed with tests. Multilevel regression analyses were conducted to analyze the significance of teachers' PCK for students' progress in elementary science classrooms. Results showed that teachers' PCK was significantly related to student achievement in elementary science after controlling for key student- and teacher-level covariates.

Keywords: teachers, pedagogical content knowledge, student outcomes, science education, hierarchical modeling

INTRODUCTION

In the research literature on teaching and teacher education, there is a shared understanding that teachers' professional knowledge is an important determinant of instructional quality that impacts students' achievement gains (Baumert & Kunter, 2006; Bromme, 1997; Munby, Russell, & Martin, 2001). Yet few empirical studies have assessed the different components of teachers' knowledge directly and separately to predict instructional quality or student outcome. The main goal of this study was to explore whether teachers' pedagogical content knowledge as a crucial component of teachers' professional knowledge makes a contribution to explaining differences in students' learning outcomes in elementary science education.

The study is part of the project PLUS (Teachers' professional knowledge, science teaching and student outcomes in the transition from primary to secondary school) that investigates conditions and outcomes of science instruction in the transition from elementary to secondary education. It was conducted in Germany from 2007 to 2010. The study, which had two measurement points, surveyed a sample of 60 elementary science classes and 54 secondary science classes and their teachers. Drawing on the elementary sample, the study at hand explored whether teachers' pedagogical content knowledge in science contributes to gains in students' understanding of scientific concepts. In order to address this question we used a newly constructed knowledge test to assess teachers' pedagogical content knowledge in the domain of science directly. Teacher data was then linked to data on student outcome, in order to determine the implications of pedagogical content knowledge for student learning.

RATIONALE

The theoretical foundation of research on teachers' professional knowledge was laid at the American Educational Research Association meeting in 1985, when Lee Shulman proposed a model for conceptualizing knowledge for teaching. There he introduced the constructs of generic pedagogical knowledge, content knowledge and pedagogical content knowledge as the core components of the specialized knowledge that is required for teaching. Although researchers have added to or specified these domains of teacher knowledge over the last decades, these three components have consistently appeared in literature and thus seem to be internationally agreed upon as core components of teachers' professional knowledge (Baumert & Kunter, 2006; Borko & Putnam, 1996; Bromme, 1997; Munby, Russell, & Martin, 2001). Knowledge of generic pedagogy (PK) is described as general, subject-independent knowledge about classroom organization and management, general knowledge of learning theory and general methods of teaching. Content knowledge (CK) includes the knowledge of a subject or discipline per se and is not unique to teaching. It goes beyond the knowledge of facts, concepts, principles and theories to also include an understanding of how concepts and principles of a subject are organized and the rules of evidence and proof that are used to justify claims in a certain subject or discipline. Within this classification of teachers' knowledge, pedagogical content knowledge (PCK) is considered the central component of teachers' professional knowledge that distinguishes teachers from subject matter specialists (Grossman, 1990; Shulman, 1987; Van Driel, Verloop, & De Vos, 1998). PCK is defined as a kind of "amalgam" of content knowledge with pedagogical and psychological knowledge as well as with the teachers' personal experiences, creating an understanding of how certain topics, problems or issues ought to be presented and adapted to the learners' different interests and abilities (Shulman, 1987). Magnusson, Krajcik and Borko (1999) proposed a model of PCK in the area of science education, defining five components. They include 'orientations towards science teaching', 'knowledge of science curricula', 'knowledge of students' understanding of science', 'knowledge of instructional strategies' and 'knowledge of assessment for science'. Recent studies on the different domains of PCK (e.g. orientations towards teaching, knowledge of students' understanding or instructional strategies) in mathematics found that teachers' mathematical PCK was positively related to students' gains in mathematical achievement (e.g. Staub & Stern, 2002; Hill, Rowan, & Ball, 2005, Baumert et al., 2010). Whereas studies in the domain of orientations towards teaching have already been established in the field of elementary science (Kleickmann, 2008), studies targeting at the further components of PCK are missing completely in elementary science. Thus, this study aims at measuring elementary science teachers' PCK directly, followed by examining its relevance for students' gains in conceptual understanding.

METHODS

Comprising 1326 fourth-graders (621 girls and 702 boys, 3 students did not indicate gender) in 60 classrooms, the data presented here stems from a project investigating the development and interplay of science instruction, classroom climate and students' science interest in the transition from primary to secondary education in Germany (PLUS Study). The cross-sectional study had a quasi-experimental design. Participating teachers were instructed to provide their classes with a series of three 90-minute lessons on the topic of evaporation and condensation. Students were tested for science achievement concerning the topic "states of matter and changes of state" both before and after the series of lessons. Teacher data were gathered from various instruments amongst others a test assessing their PCK in the domain of "states of matter".

The assessment of teachers' PCK was based on the Magnusson et al. model (1999). Considering the recent studies in mathematics that described 'knowledge of students' understanding' (KSU) and 'knowledge of instructional strategies' (KIS) as components of PCK that trigger students' achievement, the focus of the test was nested within these two components. The developed items asked teachers e.g. to list as many alternative students' conceptions as possible concerning an every-day evaporation situation (KSU). Other items presented situations in which teachers are asked to detect comprehension difficulties or to describe adequate behavior to promote insightful student learning (KIS). The final test consisted of 14 items (11 free-response-, 3 multiple-choice-items) and showed good psychometrical qualities (average ICC= .92, range: .8 - 1.0; Cronbachs $\alpha = 0.69$).

Student achievement was assessed at the end of the unit by a test covering condensation and evaporation as well as the liquid and gaseous state of matter (using water as example). The reliability of the full test (24 items in m*ultiple-choice*- or m*ultiple-select*-format) was Cronbachs $\alpha = .67$ in the pretest and Cronbachs $\alpha = .79$ in the posttest.

Multilevel analyses were used to analyze the impact of elementary science teachers' PCK on students' gains in conceptual understanding. A two-level model predicting the achievement on the posttest-score on the individual-level by teachers topic-specific PCK on the class level was specified. To account for other important predictors, we controlled for relevant student characteristic like prior knowledge, general cognitive abilities, German as native language, socio-economic background and gender as well as for critical classroom and teacher characteristics like duration of instruction, classroom-management and job experience. To account for missing data we used the full information maximum likelihood algorithm implemented in the software Mplus, which estimates the missing values (Muthén & Muthén, 1998-2009).

RESULTS

In a first step, the variance in students' achievement was decomposed into within- and between-class components. The results showed that 78.6% of the variation in achievement was within classes and that 21.4% was between classes. After controlling for the variables at the individual level, 14.4% of the variation in achievement remained between classes.

In a second step, we specified the individual model. We estimated a random intercept model with the five control variables named above. The most important predictor was that of students' topic-specific prior knowledge at the beginning of the unit, followed by general cognitive ability. Beyond that, German as native language, socio-economic background and gender proved to be less important.

In the next step, the control variables at the class level were entered in the model. The predictors at class level were: duration of instruction, quality of classroom-management and job experience. All variables proved to be significant predictors of students' learning achievement concerning "states of matter" at the end of the unit.

When PCK of elementary science teachers was entered in the model next to the control variables the results revealed a substantial positive effect of the measured PCK on students' gains in science achievement in the domain of "states of matter". Thirteen percent of the variance in achievement between classes was explained by PCK after controlling for key student- and teacher-level covariates (for detailed analyses see Lange, Kleickmann, Tröbst, & Möller, in print).

DISCUSSION AND CONCLUSION

In the presented study we constructed and implemented a test to assess primary teachers' PCK directly. In sum first analyses indicate that we succeeded in developing a reliable and valid test which was needed to answer our research questions on the impact of PCK on students' achievement gains in elementary science classrooms. When controlling for several predictors at individual and class level, we were able to show that elementary science teachers' PCK positively predicts students' gains in science achievement in the domain of "states of matter". These results are nicely in line with findings on effects of domain-specific knowledge in the field of mathematics (Baumert et al., 2010, Hill et al., 2005).

Compared to the effect sizes found in the studies in the domain of mathematics the effect sizes are rather small. It could be argued that this is a domain-specific effect. On the other hand the small effect size could be explained by the short treatment-duration of the study conducted. While the studies in the field of mathematics investigated the impact of teachers' PCK on students' learning gains over a whole school year, our study chose a topic-specific approach. Focusing on just one content area, we investigated the impact of teachers' PCK on student achievement over an average treatment duration of approx. seven lessons. Against this background, the question whether the small effect size is a domain-specific effect or not, is not answered yet. Neither is the question whether we can find an impact of PCK on students' achievement gains in other content domains within elementary science education. Further research in different science domains and studies over a longer period of time are needed to answer these questions. If these future research attempts confirmed our findings, one could tentatively conclude that it might be possible to improve students' learning gains in science by improving teachers PCK. One of the next challenges for teacher research would then be to determine how pre-service and in-service teachers can best be supported in acquiring this knowledge.

REFERENCES

Baumert, J., & Kunter, M. (2006). Stichwort: Professionelle Kompetenz von Lehrkräften [Keyword: Professional competencies of teachers]. *Zeitschrift für Erziehungswissenschaft*(9), 469-520.

Baumert, J., Kunter, M., Blum, W., Brunner, M., Voss, T., Jordan, A., et al. (2010). Teachers' mathematical knowledge, cognitive activation in the classroom, and student progress. American Educational Research Journal, 47(1), 133-180.

Borko, H., & Putnam, R. T. (1996). Learning to teach. In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 673-708). Washington: MacMillan.

Bromme, R. (1997). Kompetenzen, Funktionen und unterrichtliches Handeln des Lehrers [Teachers' competencies, functions and action in class]. In F. E. Weinert (Ed.), *Enzyklopädie der Psychologie: Psychologie des Unterrichts und der Schule* (Vol. 3, pp. 177-212).

Göttingen: Hogrefe.
Bromme, R. (1997). Kompetenzen, Funktionen und unterrichtliches Handeln des Lehrers [Competencies, functions and instruction of teachers]. In F. E. Weinert (Hrsg.), *Psychologie des Unterrichts und der Schule* (S. 177-212). Göttingen: Hogrefe.
Grossman, P. L. (1990). *The making of a teacher: Teacher knowledge and teacher education*. New York: Teachers College Press, Columbia University.
Hill, H.C., Rowan, B., & Ball, D. (2005). Effects of teachers' mathematical knowledge for teaching on student achievement. *American Educational Research Journal,* 42 (2), 371– 406.
Kleickmann. T. (2008). *Zusammenhänge fachspezifischer Vorstellungen von Grundschul-lehrkräften zum Lehren und Lernen mit Fortschritten von Schülerinnen und Schülern im konzeptuellen Verständnis* [Relations of teachers' conceptions of teaching and learning science with students' progress in understanding of scientific concepts]. Münster: Inaugural-Dissertation.
Lange, K., Kleickmann, T., Tröbst, S., & Möller, K. (in print). Fachdidaktisches Wissen von Lehrkräften und multiple Ziele im naturwissenschaftlichen Sachunterricht [Teachers' pedagogical content knowledge and multiple learning outcome in elementary science]. *Zeitschrift für Erziehungswissenschaft*.
Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge. The construct and its implications for science education* (Vol. 6, pp. 95-132).
Munby, H., Russell, T., & Martin, A. K. (2001). Teachers' knowledge and how it develops. In V. Richardson (Ed.), *Handbook of research on teaching* (fourth ed., pp. 877-904). Washington: American Educational Research Association.
Muthén, L. K., & Muthén, B. O. (1998-2009). *Mplus statistical analysis with latent variables: User's guide* (5 ed.). Los Angeles, CA: Muthén & Muthén.
Richardson, V. Placier, P. (2001). Teacher Change. In V. Richardson (Ed.), *Handbook of Research on Teaching* (pp. 905-947).
Shulman, L. S. (1987). Knowledge and teaching: Foundations of the New Reform. *Harvard Educational Review*, 57(1), 1-22.
Shulman, L. (1986). Those who understand: Knowledge Growth in Teaching. *Educational Researcher*, 15 (2), 4–14.
Staub. F., & Stern. E. (2002). The nature of teachers' pedagogical content beliefs matters for students' achievement gains: Quasi-experimental evidence from elementary mathematics. *Journal of Educational Psychology*, 93, 344–355.
Van Driel, J. H., Verloop, N., & De Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching*, 35(6), 673-695.