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Kompetenzerwerb zukünftiger LehrerInnen in der universitären Ausbildung

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What Is the Relationship Between Knowledge in Mathematics and Knowledge in Economics?

Investigating the professional knowledge of (pre-service) teachers trained in two subjects[1]

Abstract: Content knowledge (CK) and pedagogical content knowledge (PCK) are considered key aspects of teacher competence. Although teacher education and training programs across disciplines focus on the development of CK and PCK, there is little evidence of whether teachers trained in two subjects benefit from reciprocal effects between knowledge in these subjects. To approach this question, we investigated the correlation between the CK and PCK in mathematics and economics of $N = 96$ pre- and in-service teachers trained in both subjects. We found a substantial correlation between CK and PCK within a subject and between corresponding knowledge components across subjects, with CK in mathematics related also to PCK in economics. We found that although teachers' professional knowledge structure mirrored domains, CK in mathematics could be useful for teaching economics.

Keywords: Teacher Knowledge, Teacher Education, Content Knowledge, Pedagogical Content Knowledge, Mathematics, Economics

1. Introduction

The importance of teachers' professional knowledge for teaching quality has been shown in teacher education research across disciplines (Halim & Meerah, 2002; Hill, Rowan & Ball, 2005). Teachers' content knowledge (CK) and pedagogical content knowledge (PCK) in particular have been identified as powerful predictors for instructional quality and student learning across subjects (Baumert et al., 2010; Keller, Neumann & Fischer, 2017). From a teacher education perspective, PCK is of particular interest, as it can be considered an "amalgam of content and pedagogy" that is distinctive for teaching (Shulman, 1986, p. 8). Consequently, PCK is regarded as crucial for high-quality instruction (Park & Oliver, 2008; Sorge, Kröger, Petersen & Neumann, 2017).

However, despite the relevance of subject-specific teacher knowledge, research has not yet comprehensively explained how teachers acquire that knowledge in different school subjects (Zlatkin-Troitschanskaia, Shavelson & Kuhn, 2015). Particularly with regard to upper-secondary teacher training programs in Germany, in which teachers

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are trained to teach two subjects, no research has been conducted on whether and how the teachers' knowledge in one subject relates to the their knowledge in another subject (Stancel-Piatak et al., 2013). The focus of most studies has been knowledge in one subject only (e.g., professional knowledge of mathematics teachers). Teachers of two related subjects (e.g., mathematics and economics) may benefit in particular from this combination, as some subject-specific knowledge may be useful for teaching other subjects.

In the present paper, this research deficit is addressed as investigation is made into the professional knowledge of teachers of mathematics and economics, two subjects which are different but related, as mathematics plays an important role in economics. The aim is to gain empirical evidence of whether and how teachers' knowledge in one subject, mathematics or economics, relates to their knowledge in the other subject.

2. Research on Subject-Specific Teacher Knowledge

According to Shulman (1986), subject-specific teacher knowledge has two facets: CK and PCK. CK is described as teachers' understanding of subject matter and includes not only an understanding '*that* something is so' but also an understanding of '*why* something is so' (Shulman, 1986, p. 9). CK is a deep understanding of the subject matter that is relevant in school (Kleickmann et al., 2013). To date, operationalisations of teachers' CK for various subjects are available (e.g., mathematics: Baumert et al., 2010; Dreher, Lindmeier, Heinze & Niemand, 2018; economics: Zlatkin-Troitschanskaia et al., 2015). In contrast, PCK is described as the knowledge teachers need to make subject matter accessible to students (Depaepe, Verschaffel & Kelchtermans, 2013; Kuhn, Alonzo & Zlatkin-Troitschanskaia, 2016). According to Shulman's description of PCK as an amalgam of content and pedagogy, it can be assumed that PCK contains non-subject-specific aspects (e.g., pedagogical knowledge) and subject-specific aspects. Across disciplines, there is some consensus that teachers' PCK includes *knowledge of student cognition, knowledge of explanations and multiple representations,* and *knowledge about the potential of tasks* (Depaepe et al., 2013).

Following these conceptualizations, an extensive body of research has been conducted on the effect of teachers' CK and PCK, and a significant correlation has been found to students' achievement, for instance, in terms of mathematical understanding (Hill et al., 2005). Especially for providing subject-specific instruction that is cognitively activating and constructively supportive for students, PCK has been found to be even more important than CK (Baumert et al., 2010). However, despite the many studies of teachers' CK and PCK, little is known about how subject-specific knowledge in various subjects is related when teachers are trained in two subjects.

2.1 Acquiring CK and PCK in Mathematics and Economics

In Germany, teacher education has three stages: The first, theoretical stage takes place at university and comprises three years of bachelor studies and two years of master studies. The second stage consists of one and a half to two years of supervised practical training at schools. The third stage involves professional, fully autonomous teaching at schools. Universities are the constitutive place for learning opportunities with regard to teacher knowledge (Kleickmann & Anders, 2013) and the main focus of teacher education programs especially at the bachelor level is to develop CK. The programs are structured mainly according to subjects. Training in PCK is also emphasized in university teacher training programs, but usually at the master level (Kuhn, 2014; Tröbst et al., 2018). It has been argued that teachers can transform CK into PCK without having special training to develop PCK, for example, by integrating general pedagogical knowledge (Lannin et al., 2013). This assumption sometimes has been supported by correlations found between CK and PCK of pre-service mathematics teachers (Krauss et al., 2017) and the finding of studies that teachers of academic-track mathematics (strong focus on CK) outperform teachers of non-academic-track mathematics on tests of PCK (Baumert et al., 2010; Tröbst et al., 2018). Results of studies in which comparison is made between mathematicians and mathematics teachers indicate that mathematicians performed more poorly on items testing components of PCK that are important for planning instruction (Krauss, Baumert & Blum, 2008). Thus, it is argued that opportunities to develop CK do not suffice to develop PCK; rather, opportunities to develop PCK are needed (Kuhn, 2014; Riese & Reinhold, 2012). Findings on the relationship between CK and PCK in subjects other than mathematics support this argument, as they sometimes show considerably weaker correlations between the knowledge constructs. This suggests that CK and PCK are two related but separable constructs which require targeted training (for economics: Kuhn, 2014; for English: Roters, Nold, Haudeck, Keßler & Stancel-Piatak, 2011; for physics: Riese & Reinhold, 2012; for seven subjects including languages and arts: Krauss et al., 2017). However, while the acquisition processes of PCK are not yet sufficiently understood, CK commonly is considered a prerequisite for developing PCK (Depaepe et al., 2013).

The focus of research on prerequisites for the acquisition of teacher knowledge has been cognitive abilities and prior knowledge (Kleickmann & Anders, 2013; Kuhn, 2014). Cognitive abilities generally are seen as a stable individual resource for further learning. Prior knowledge refers to knowledge prospective teachers acquired at school (i.e., as indicated by their school-leaving grade) indicating their preparedness for further learning (Tröbst et al., 2018).

To summarize, research on teacher's subject-specific professional knowledge usually has been conducted within one subject. This may be due to the fact that in most countries secondary school teachers are trained in one subject only, and national studies (TEDS-LT: Buchholtz & Kaiser, 2013; FALKO: Lindl & Krauss, 2017) usually are not of appropriate samples of teachers trained in different school subjects. Hence, there is currently a lack of evidence of whether professional knowledge, PCK and especially

CK in one subject may promote teacher knowledge in the other subject. This question is of broader relevance for teacher training, especially with a view on related subjects with a potential for synergies.

2.2 Hypothesized Relationships Between Teacher Knowledge in Mathematics and Economics

Although mathematics and economics are two different domains, individuals' performance on mathematics tests and their performance on economics tests are correlated (Ballard & Johnson, 2004; Williams, Waldauer & Duggal, 1992). This can be traced back to the theoretical conceptualizations of mathematics as being one facet of CK in economics, and so the domains are considered related (Deutscher & Winther, 2015). It can be assumed that teacher knowledge particularly in mathematics may foster the acquisition of teacher knowledge in economics in all three phases of teacher education (university phase, training phase, and in-service teaching phase). It is possible that some aspects of CK and PCK in mathematics are important for teaching economics and could be integrated into CK and PCK in economics (e.g., CK in mathematics could integrate into PCK in economics when students have mathematics-related issues performing an economics-related task). Thus, the following relationships between teachers' CK and PCK in mathematics and economics can be expected:

1) *Relationship to CK.* As mathematics is used to describe and solve economic problems, it can be considered an essential part of economics and crucial for studying economics at university (Ballard & Johnson, 2004). For instance, Williams et al. (1992) showed that performance in mathematics is a major determinant of success in economics studies. CK in mathematics may therefore promote the acquisition of CK in economics. Since economics is a field in which mathematical concepts are applied, CK in economics could also be expected to deepen CK in mathematics. Thus, a relationship between CK in economics and CK in mathematics can be expected.
2) *Relationship to PCK.* According to preliminary findings that CK in a subject is a prerequisite for acquiring PCK in the same subject, a certain degree of understanding of the subject matter is required for the development of PCK (Kleickmann et al., 2013; Kuhn, 2014; Tröbst et al., 2018). It can therefore be assumed that there is a significant connection between CK and PCK within a subject (i.e., mathematics and economics). Beyond that, (school) mathematics is an essential part of (school) economics as well. Hence, it can be assumed that economics teachers' CK in mathematics as well as their PCK in mathematics improve not only their understanding of economics students' misconceptions caused by mathematics-related issues, but also their ability to explain economics-related problems (e.g., using/avoiding mathematics) and their ability to analyse economics-related tasks (requiring some knowledge of mathematics). Hence, CK and PCK in mathematics might affect all aspects of PCK in economics (Kuhn, 2014; Tröbst et al., 2018). In particular, CK in mathematics

may not only be relevant for CK in economics but also improve the acquisition of PCK in economics. In contrast, taking the conceptualization of PCK in mathematics into account, there is no reason to assume CK in economics influences the acquisition of PCK in mathematics. Finally, it is reasonable to assume mutual influences of PCK in mathematics and economics, as PCK in different subjects is assumed to comprise some common pedagogical and psychological elements (Shulman, 1986). For instance, similarities in the fundamental teaching principles of the subjects can be found, such as the principle of action (Prinzip der Handlungsorientierung) used in teaching mathematics and economics (Aebli, 1985; Riedel, 2006). Moreover, the simultaneous acquisition of PCK in two different subjects may deepen understanding of the structure of PCK as an amalgam of content and pedagogy.

3. Research Questions and Hypotheses

Summarizing the current state of research, there is no empirical evidence of a connection between teacher knowledge in two subjects. With respect to mathematics and economics teachers, interrelations between CK and PCK can be hypothesized based on theoretical considerations. Thus, we pursued the following research question: *How are components of professional knowledge in mathematics (M-CK, M-PCK) and components of professional knowledge in economics (E-CK, E-PCK) related in teachers of both subjects?*

Based on the theoretical assumptions outlined above, we assume:

1) a significant moderate relationship between M-CK and E-CK, as we assume knowledge in mathematics facilitates understanding of economics.
2) a significant but weak relationship between M-CK and E-PCK, as we assume knowledge of school-level mathematics is useful when teaching economics. We expect this relationship to be smaller than (1), as E-CK already mediates the mathematics knowledge needed to understand economics.
3) a weak correlation between E-PCK and M-PCK due to the common core of pedagogical and psychological knowledge.

4. Method

4.1 Study Design and Sample

We analysed the subject-specific professional knowledge of (prospective) upper-secondary teachers trained in mathematics and economics. Although secondary school teachers in Germany are trained in two subjects, a specific combination such as mathematics and economics limits our target group. This combination of interest is particularly attractive for upper-secondary school teachers with a vocational focus (Berufsschule).

To obtain an adequate sample, we targeted pre-service and in-service teachers of general and vocational schools. We recruited participants from universities, teacher training (Referendariat) colleges, and schools from 52 cities in 10 German federal states. Student teachers at universities had to be in the second half of their study program in order to participate. Participation was voluntary, and a monetary incentive was offered as compensation.

The final sample comprised $N = 96$ (prospective) teachers (55% female) of both subjects, mathematics and economics: $n = 54$ students (age $M = 27.6$ years, $SD = 5.7$), $n = 17$ trainees ($M = 29.8$, $SD = 2.8$), and $n = 25$ in-service teachers ($M = 40.2$, $SD = 7.2$).

4.2 Measures

To assess professional knowledge in mathematics and economics, we used short scales of established, field-tested paper-pencil tests for M-CK (14 items), E-CK (15 items), M-PCK (15 items), and E-PCK (11 items). Measures for CK contained items relevant for secondary level education (see Fig. 1 and 2) and measures for PCK contained items relevant for teachers' knowledge of student cognition, potential of exercises and content representations (see Fig. 3 and 4) in mathematics and economics, respectively. Validity evidence based on test content, response processes, internal structure, and relationships to other variables is given for all instruments (for a detailed description see Heinze, Dreher, Lindmeier & Niemand, 2016 for M-CK, Zlatkin-Troitschanskaia, Förster, Schmidt, Brückner & Beck, 2015 for E-CK, Loch, Lindmeier, & Heinze, 2015 for M-PCK and Kuhn, 2014 for E-PCK). The instruments contained closed- and open-ended items that were coded by student assistants trained to use detailed codebooks. We found acceptable to very good interrater agreements for M-CK and M-PCK of Cohen's $\kappa = .70–1.00$ ($M = .89$) as well as for E-PCK of Cohen's $\kappa = .60–.89$ ($M = .78$) based on at least 20% of the open responses (randomly selected) for each item. Reliabilities (Cronbach's Al-

The field of real numbers $\mathbb{R}$ can be mathematically constructed from the rational numbers $\mathbb{Q}$ in several ways. Which manner of construction is suited as a reduction for the mathematics classroom? Please assume that the existence of examples for irrational numbers were already shown, as usual.

	True	False
$\mathbb{R}$ is constructed from $\mathbb{Q}$ by means of the topological closure.	❑	❑
$\mathbb{R}$ is constructed from $\mathbb{Q}$ by means of fundamental (Cauchy) sequences.	❑	❑
$\mathbb{R}$ is constructed from $\mathbb{Q}$ by means of nested intervals.	❑	❑
$\mathbb{R}$ is constructed from $\mathbb{Q}$ by means of Dedekind cuts.	❑	❑

Fig. 1: Sample item for M-CK (complex multiple choice)

Which monetary policy would the Federal Reserve most likely adopt as the economy moves into a recession during a period of low inflation?
❑ Lower the federal funds rate.
❑ Increase federal income tax rates.
❑ Decrease purchases of government bonds.
❑ Raise the reserve requirements for banks.

Fig. 2: Sample item for E-CK (single choice)

Please draw an illustration to explain to a 6th grade student how to multiply a fraction by another fraction. Take $^1/_4 \times {}^2/_3$ as an example.

Fig. 3: Sample item for M-PCK (open response)

You are teaching an advanced class. Your students of wholesaling and foreign trade have learned how to choose suppliers based on a quantitative comparison of the offers (price as decision criterion). Your aim now is to ensure that students can make decisions by considering uncertain factors. Your starting point is the following task for your students.
You are a salesperson for cell phones and receive an offer by a supplier of cell phone cases for a total amount of €500. The supplier grants you a discount of 15%. Furthermore, if payment is made within eight days, an additional cash discount of 2% will be granted. *Work in teams and calculate and evaluate the purchase price!* How would you alter the task to achieve your aim? Give two specific options. (In bullet points, please.) **1.** **2.**

Fig. 4: Sample item for E-PCK (open response)

pha) were α = .62 (M-CK), α = .65 (M-PCK), α = .60 (E-CK) and α = .64 (E-PCK), which is marginally sufficient considering the scale length and the conceptual heterogeneity of CK and PCK that has been previously found to cause minimal internal consistencies (Blömeke et al., 2015; Hill, Schilling & Ball, 2004).

In addition, we asked the participants to state their school-leaving grade point average (GPA) and measured their general cognitive abilities (GCA, I-S-T 2000 R, figural analogies, 20 single choice items, Cronbach's α = .78; Liepmann, Beauducel, Brocke, & Amthauer, 2007), to control for individual differences that might impact knowledge acquisition.

4.3 Data Analysis

We specified a path model according to the theoretical assumptions and conducted a linear regression analysis. The path model was further refined with GCA and GPA as an exogenous variable. We used sum scores as indicators for the four knowledge constructs and GCA. All path models were saturated with regression paths between all variables. The analyses were computed using the "lavaan" package (Rosseel, 2012) and R software (version 3.5.1).

A multiple group analysis comparing participants with teaching experience and those without ($n = 42$ teacher trainees and in-service teachers vs. $n = 54$ student teachers) showed that, for the path model without GCA/GPA, the same model parameters sufficiently described the data of both groups (model fit with constrained parameters: CFI = .98, RMSEA = .07, SRMR = .06). Thus, a combined sample was studied in the remaining analyses and the subsamples are no longer differentiated.

5. Results

In Table 1 the descriptive statistics for all scales as well as their correlations are shown. As expected, the strongest correlations can be found between CK and PCK within one subject (mathematics: $r = .49$, $p < .001$; economics: $r = .41$, $p < .001$). Moreover, significant correlations are found between the same constructs (CK, PCK) across mathematics and economics. However, as Pearson correlations do not control for shared variance with other variables, those relationships might, at least in part, be due to mediation effects.

To control for such effects, we estimated the specified path model (Figure 5). The parameter estimates support significant correlations between CK and PCK within each subject (mathematics: $\beta = .50$, $p < .001$; economics: $\beta = .34$, $p < .001$). The results indicate further significant to weak relationships between the same constructs across subjects (M-CK and E-CK: $\beta = .36$, $p < .001$; M-PCK and E-PCK: $\beta = .21$, $p = .04$). Furthermore, we find a weak relationship between M-CK and E-PCK ($\beta = .20$, $p = .04$). No correlation was found between E-CK and M-PCK ($\beta = -.01$, $p = .90$). In total, approximately 24% of the variance in M-PCK and 20% in E-PCK was explained.

To control for GCA and GPA, we computed two more path models including these variables as covariates affecting all other variables. The results indicate that neither GCA nor GPA significantly correlated to the four knowledge variables (GCA: $|\beta| < .08$, $p > .43$; GPA: $|\beta| < .05$, $p > .69$) and, thus, none of the regression coefficients changed substantially (GCA: $|\Delta\beta| < .008$; GPA: $|\Delta\beta| < .03$). Accordingly, we discarded those models in favor of the simpler model without CGA or GPA.

Variables	M-CK	E-CK	M-PCK	E-PCK	GCA	GPA
M-CK	–					
E-CK	.36***	–				
M-PCK	.49***	.16	–			
E-PCK	.32**	.41***	.31**	–		
GCA	−.08	.02	−.06	−.01	–	
GPA	.04	.01	.04	.06	−.01	–
Scale mean	11.15	7.96	9.41	6.32	11.31	2.1
SD	4.57	2.75	3.78	3.10	4.68	0.54
Theoretical scale maximum	28	15	27	17	20	4.0

Tab. 1: Pearson Correlations and Descriptive Statistics for CK and PCK in Mathematics (M-) and Economics (E-) Scales, General Cognitive Abilities (GCA) and GPA (p < .05, ** p < .01, *** p < .001)*

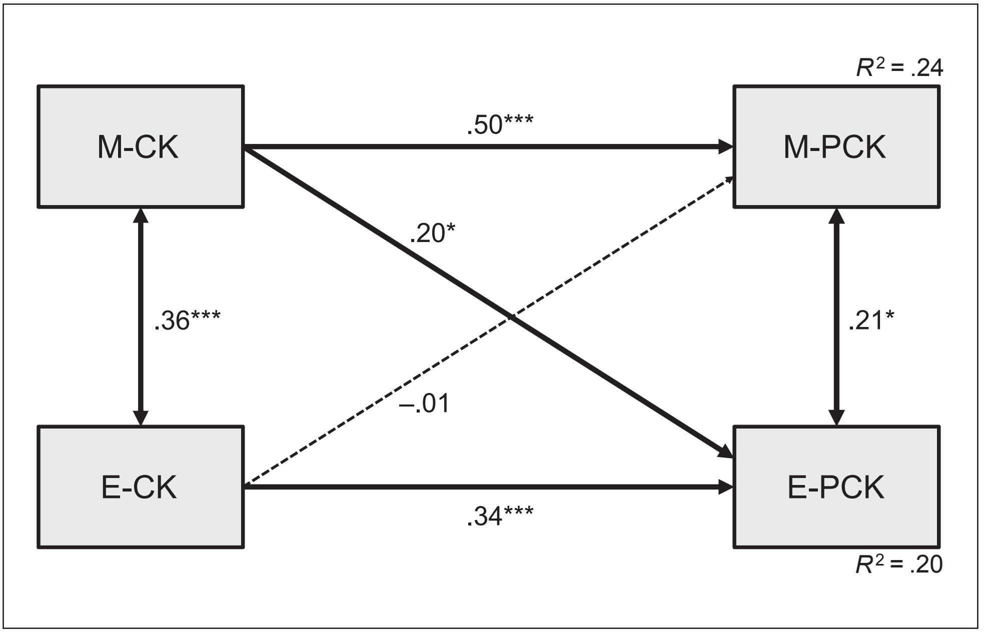

Fig. 5: Path model with standardized weights relating CK and PCK in mathematics (M-) to CK and PCK in economics (E-). Paths with significant effects are presented with bold lines and asterisks (p < .05, ** p < .01, *** p < .001). CFI = 1, RMSEA = 0 (saturated model)*

6. Discussion

The aim of this study was to gain preliminary empirical evidence of how teachers' professional knowledge in one subject is related to their professional knowledge in another subject. We analysed data of (prospective and practicing) teachers trained in both mathematics and economics. As expected from a theoretical perspective, we found significant correlations between CK and PCK within mathematics and economics. This result is consistent with previous findings (e.g., Heinze et al., 2016; Kuhn, 2014) and supports our hypotheses, as CK usually is considered a prerequisite for PCK within a subject. The correlation tends to be stronger in mathematics; however, the difference is not statistically significant. This may reflect the hypothesis that mathematics is a more structured domain than economics (Gruber & Mandl, 1996). Against our expectations, we did not find significant correlations between teacher knowledge and GPA or GCA. This may be due to the fact that such correlations are relatively small compared to those between teacher knowledge components (Kleickmann & Anders, 2013). In comparison to other studies, our teachers' academic background was less diverse. Further, our GCA measure stemmed from a short scale; therefore, variances might have been reduced. This may have masked possible correlations and therefore they were not detectable in our study. Across subjects, we found correlations between M-CK and both E-CK and E-PCK, which are not further mediated by E-CK. This meets our expectations, as CK in mathematics could be relevant for teaching economics beyond the extent that mathematics is required for understanding economics. In contrast, we found no correlation between E-CK and M-PCK, which was expected as well. In addition to a correlation between the constructs of CK in both subjects, a weak correlation was found between the constructs of PCK in both subjects. Given that in our analysis we controlled for effects of CK, we see shared variance in PCK in different subjects not explained by the affinity of the domains. Results of our study do not explain the origin of this correlation, but it is in line with the assumption that constructs of PCK in different school subjects might share a common core of pedagogical knowledge (Shulman, 1986). Further investigation should be made into this assumption.

Some additional limitations of the study should be noted. First, although the participants in the sample were well distributed across 50 locations in Germany, the sample selected cannot be considered representative. The small sample size of in-service teachers in particular may have influenced the results. It is possible that we underestimated some of the identified correlations due to the sample size and marginally sufficient scale reliabilities. Second, our inter-individual analyses of cross-sectional data permitted correlational interpretation only. To gain evidence of how components of teacher knowledge affect each other causally, in future studies investigation should be made into intra-individual variance of, for example, longitudinal data (Asendorpf, 2018; Renkl, 2012).

Despite these limitations, this study provides some insightful evidence of how professional knowledge of teachers interrelates between school subjects. This is of interest not only for countries such as Germany, where teachers are trained in two subjects, but also for teacher training in general. First, our data confirm that PCK is more clearly part of subject-specific knowledge than of knowledge in multiple subjects. Second, as greater CK in mathematics correlated to greater PCK in economics, there is reason to conjecture that comprehensive training to develop CK in mathematics can impact the development of PCK in subjects related to mathematics, such as economics, but not vice versa. These findings might be of particular interest for the training of out-of-field teachers, for example, where programs might benefit from research-informed designs depending on the prior qualifications of teachers. Based on the findings of this study, future research should investigate the extent to which our results reflect conditions of acquisition and are generalizable for other subjects as well.

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Zusammenfassung: Fachwissen (CK) und fachdidaktisches Wissen (PCK) gelten als wichtige Bestandteile professioneller Kompetenz von Lehrkräften. Hinsichtlich der Ausbildung in zwei Schulfächern ist bislang jedoch wenig erforscht, inwieweit der Wissenserwerb in einem Fach durch die Ausbildung in einem weiteren Schulfach beeinflusst wird. In dieser Studie werden Zusammenhänge zwischen CK und PCK der Fächer Mathematik und Wirtschaftswissenschaften bei N = 96 angehenden und praktizierenden Sekundarstufen-Lehrkräften mit dieser Fächerkombination untersucht. Die Ergebnisse zeigen substantielle Zusammenhänge zwischen CK und PCK innerhalb der Fächer und zwischen den professionellen Wissenskonstrukten über die Fächer hinweg, wobei CK in Mathematik auch mit PCK in Wirtschaftswissenschaften zusammenhängt. Obwohl die Wissensbasis einer Lehrkraft eine Strukturierung nach Fächern abbildet, könnte CK in Mathematik für das Unterrichten von Wirtschaftswissenschaften förderlich sein.

Schlagworte: Lehrerwissen, Lehrerausbildung, Fachwissen, fachdidaktisches Wissen, Mathematik, Wirtschaftswissenschaften

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