Research article

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Why school-related content knowledge for pre-service chemistry teachers should include basic concepts in organic chemistry

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Abstract: In this paper we describe and evaluate a study on the use of concepts in organic chemistry while solving tasks that are designed after the concept of school-related content knowledge (SRCK). The study was designed as a mixed methods study and conducted at a German university for the content of "organic chemistry". As the results of this study show, the students rate the tasks and the use of anchoring concepts as for example "bonds" or "structure and function" as relevant for their future profession as a chemistry teacher. They therefore propose that concepts should be an integral part of their university studies as they find it lacking at the moment. Concepts can also be seen as an opportunity to build a bridge between school knowledge and university knowledge.

Keywords: anchoring concepts; content knowledge; organic chemistry; pre-service chemistry teachers.

Introduction

Since Shulman's definition of the professional knowledge of teachers (Shulman, 1986) as content knowledge (CK), pedagogical content knowledge (PCK) and pedagogical knowledge (PK) there is a continuous discussion about the knowledge and skills a teacher should have. For CK, several approaches and constructs have been published in recent years. All concepts for science teachers have in common that there is an apparent need of a specific knowledge for this profession (Ball, Themes, & Phelps, 2008). However, the names of the knowledge types are different although "deeper school knowledge" (Riese, 2009) or "school-related content knowledge (SRCK)" (Woehlecke et al., 2017) describe a similar knowledge category. The CK of (prospective) physics teachers is divided by Riese (2009) in school knowledge, deeper school knowledge and university knowledge. Woehlecke et al. (2017) divides the CK in school knowledge, SRCK and university knowledge. Both descriptions refer to the specific CK for prospective teachers. University teachers have to decide which knowledge is part of their university courses. As theoretical background for our courses and research we rely on the construct by Woehlecke et al. (2017). This construct consists of the following three facets:

– Knowledge of concepts and their application in the respective subject,
– Knowledge of learning processes including subject-specific theories, terminologies, epistemological- and validity principles (comment by the authors: at university for the learning process of the pre-service chemistry students),
– Knowledge to adapt complexity meaningfully and anticipatorily.

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For a deeper understanding of contents that are relevant for teaching at school, this SRCK is necessary. For pre-service physics and chemistry teachers SRCK-specific tasks have been designed and used in university courses. The tasks for pre-service physics teachers were evaluated by a questionnaire with regard to their perceived relevance for their future profession (Massolt & Borowski, 2018, 2020). The tasks based on the SRCK-construct were recognized as more relevant than conventional physics problems by the students. The development and application of SRCK-tasks in organic chemistry were evaluated in several studies by Hermanns (2019, 2020). The category “SRCK” in organic chemistry was examined in a Delphi study. Experts (teachers and professors at university) rated tasks related to the use of school knowledge, SRCK and university knowledge. The SRCK was rated as being useful for teachers at school (Hermanns & Thomanek, 2020). The students who solved the SRCK-tasks in their seminars rated the content and the type of the tasks as being relevant for their future profession (Hermanns, 2020). For the rating, one criterion is very important: the content of the task is perceived as being more relevant if it is part of the school curriculum. For this assessment the students rely on their own learning biography; if they remember the content from their own school days, they rate this content as relevant.

Many courses on organic chemistry are organized following functional groups. They often focus on factual knowledge and not on connecting concepts. This often leads to rote memorization of the content by the students (Grove & Bretz, 2012). Therefore, when studying organic chemistry concepts of organic chemistry should also be an integral part of the courses. As described by Woehlecke et al. (2017), such concepts are elementary for connecting the school knowledge with university knowledge. Therefore concepts are one of the three facets of their SRCK-construct. For chemistry lessons at school such basic concepts are described in the school curriculum. For chemistry as a discipline, Atkins developed the “great ideas of chemistry” and asked which concepts should be taught to students (Atkins, 1999). As a result nine fundamental ideas were named, as for example “chemical bonds” or “the orbital structure of atoms”. The Division of Chemical Education of the American Chemical Society also developed concepts – the Anchoring Concepts Content Maps (ACCM) for structuring the content of university studies (Raker, Holme, & Murphy, 2013). Two examples for the Big Ideas of the ACCM are “atoms interact via electrostatic forces to form chemical bonds” or “chemical compounds have geometric structures that influence their chemical and physical behaviors”. The National Research Council of the USA developed a Framework for K-12 Science Education (National Research Council, 2012) which includes Core Ideas. These are ideas that are central for the discipline and provide the underlying support for a wide range of concepts across the discipline (Cooper, Posey, & Underwood, 2017). In our study, which is described below, we combined SRCK-tasks with anchoring concepts (Raker et al., 2013).

Design of the study

The study was designed as a mixed methods study (see Table 1) and conducted in summer 2020 with students of the courses “Organic Chemistry I” and “PCK in chemistry” for pre-service chemistry teachers. For validating which anchoring concepts are needed for the SRCK-tasks, an expert rating was conducted. With the results of this rating, the questionnaires for the students’ rating were developed. In two rounds, SRCK-tasks were solved and rated by the students. The second round included also a focus group interview with those students who solved and rated the third task. The communication during the study was completely online because as a consequence of the corona virus crisis all teaching was online. To ensure anonymity, the solutions and ratings were collected by a third person who was not involved in the evaluation of the study. This person then sent the students’ work anonymously to the researchers. All elements of the study are described below.

Goal

For this study the following research questions will be evaluated and answered:
(1) How do the students solve the SRCK-tasks that were part of this study?
(2) How do the students rate the relevance of the SRCK-tasks for their future profession?

Table 1: The mixed methods design of the study.

Content	Instrument	Method
Expert rating on SRCK-tasks with anchoring concepts	Questionnaire with yes/no option	Quantitative
	Open questions	Qualitative
Students' rating of two SRCK-tasks with anchoring concepts	Solving of the tasks	Qualitative
	Questionnaire with yes/no option	Quantitative
	Open questions	Qualitative
	Questionnaire with a 4-item Likert scale	Quantitative
Students' rating of the third SRCK-task with anchoring concepts	Solving of the tasks	Qualitative
	Questionnaire with yes/no option	Quantitative
	Open questions	Qualitative
	Questionnaire with a 4-item Likert scale	Quantitative
Reasons for the evaluation of the SRCK-tasks with anchoring concepts	Focus group interview with students	Qualitative

(3) What attitude do pre-service chemistry teachers have towards concepts in organic chemistry?
(4) How do the students rate the usefulness of the anchoring concepts for solving tasks?
(5) In what way do concepts build a bridge between university and school knowledge as defined by the SRCK-concept?

Sample

The expert rating of the task was conducted by six educators with experience in teaching organic chemistry.

For the rating of the tasks, students from the course "Organic Chemistry I" (bachelor) and from the course "PCK in chemistry" (master) participated. In the first round of rating (rating of two tasks), 16 students participated. They received 10 Euro as compensation for their time. In the second round (rating of the third task and focus group interview), five students (3 m, 2 f) participated. Two students were in their master studies and three in their bachelor studies. They received 20 Euro as compensation for their time. The students were informed about the goal of the study and the use of the data; ethical guidelines were followed. The approval of the institutional review board is not required at German universities.

Development and use of the questionnaires

For the expert rating a questionnaire was developed. The questionnaire consisted of a quantitative part with questions in a yes/no answering format and open questions to explain the reasons for answering the questions. The experts received two SRCK-tasks and an overview of the 10 Big Ideas after the ACCM (Raker et al., 2013). The experts should rate which big ideas are needed for solving the task at hand and explain their choice. The goal of the study was explained. Statistical data on the teaching and/or research experience were also collected. All questionnaires were coded to ensure that they could be assigned and compared.

Based on the results of the expert rating, the questionnaires for the students' rating were developed. The tasks were rated using a questionnaire with a 4-item Likert scale (Allen & Seaman, 2007). For the perceived relevance of the tasks, the eight items from an existing questionnaire (Hermanns, 2020) were used. In addition, five items on the topic of concepts were added (see Table 2). The big ideas were rated with the same yes/no questions as in the expert rating. The students also explained their choice. The results of the expert rating were used to make a preselection of the ideas. For the first round, eight big ideas were included, for the second round 10. The students also had to solve the tasks.

Table 2: The questionnaire for the students' rating.

	Strongly disagree	Disagree	Agree	Strongly agree
The technical content of the task is important for my future profession.				
The nature of the task is important for my future profession.				
The context of the task is realistic.				
In order to complete the task, I have to apply my university expertise.				
In order to complete the task, I have to apply my school knowledge.				
The task promotes my technical language.				
The task promotes my ability to communicate.				
The task promotes my ability to explain facts.				
The included concepts are important for my future profession.				
The selection of the concepts that were used was easy.				
The task supports the understanding of anchoring concepts.				
The concepts support the solving of the task.				
Anchoring concepts of organic chemistry give the chance of better understanding the content.				
Concepts in organic chemistry build a bridge between university and school knowledge.				

The focus group interview

The focus group interview was conducted via an online conference tool. To ensure anonymity, the students did not use their camera and used when speaking a number that was assigned to them. For the interview, a manual with several questions belonging to four categories was developed and used (see Table 3).

Table 3: The manual for the focus group interview.

Category	Examples for questions
Introduction/general	Do you think that the concepts match with the content of organic chemistry?
	Did you understand the concepts?
Use/usefulness	Did the concepts help you while solving the tasks?
	Which chances and risks do you see when concepts are discussed?
Concepts in university studies	The choice of the concepts is personal. What is your opinion to this?
	What role have the concepts played in your studies so far?
Concepts at school	Which meaning can concepts have in school?
	Would you want to optimize the basic concepts of the school curriculum?

Results and discussion

The expert rating

For the expert rating, the two tasks from round 1 were used: "Johanna and Tim" and "schoolbook". All experts teach organic chemistry; five also are researchers in this field. All experts use anchoring concepts in their courses. The information on the Big Ideas (Raker et al., 2013) was in their view not sufficient; this was taken into account by designing the questionnaires for the students. All descriptions of the Big Ideas were made anew and contained more information. The experts' voting which Big Ideas are necessary for solving the tasks was compared with the view of the co-author (bachelor student). If the experts' agreement was at least 50%, the Big Idea was included in the questionnaire. Only for one Big Idea there was no agreement between experts and co-author; the experts voted for including the Big Idea on "energy and thermodynamics" which the co-author wouldn't have included. From their view this is not surprising, because organic chemistry courses seldom focus on this concept explicitly. For the first round (tasks 1 and 2) eight Big Ideas were rated as necessary, they were therefore included in the questionnaire. The Big Ideas "intermolecular forces" and "chemical equilibrium" were not included.

Research question 1: how do the students solve the SRCK-tasks that were part of this study?

The solutions of the students were analyzed according to Kuckartz (2016) using the method of qualitative content analysis. The coding of the solutions included three categories: predominantly wrong, partly correct and predominantly correct. Predominantly wrong means that the solution contains more wrong than right answers or is incomplete. Partly correct means that the solution contains more right than wrong answers or only few small mistakes. Predominantly correct are extensive right solutions. This assignment was done by both authors who did not differ from each other. Table 4 shows the results of this analysis.

Table 4: Results of the students' solving of the tasks.

Rating	Task 1	Task 2	Task 3
Predominantly wrong	18.7%	0.0%	0.0%
Partly correct	31.3%	25.0%	60.0%
Predominantly correct	50.0%	75.0%	40.0%

Relative frequency in %.

As the results show, the tasks were mostly solved partly or predominantly correct. We therefore conclude that the students' knowledge of organic chemistry is sufficient for the rating of the tasks and the concepts.

Research question 2: how do the students rate the relevance of the SRCK-tasks for their future profession?

Although the students' rating of SRCK-tasks is known from the literature (Hermanns, 2020; Massolt & Borowski, 2018), we included the rating in this study. We wanted to know whether the students who participated in this study rated the tasks in a similar way as the students in previous studies. There it was shown that the students rated SRCK-tasks as relevant for their future profession. Table 5 shows the results of the rating in this study. For task 1, one student did not fill out the questionnaire. Therefore, *N* is here only 15.

Table 5: The students' rating of the tasks.

	Task 1 ($N = 15$) M (SD)	Task 2 ($N = 16$) M (SD)	Task 3 ($N = 5$) M (SD)
The technical content of the task is important for my future profession.	2.60 (0.910)	3.69 (0.602)	3.20 (0.447)
The nature of the task is important for my future profession.	3.73 (0.704)	3.56 (0.629)	3.80 (0.447)
The context of the task is realistic.	3.67 (0.617)	3.56 (0.629)	3.40 (0.894)
In order to complete the task, I have to apply my university expertise.	4.00 (0.000)	3.81 (0.629)	4.00 (0.000)
In order to complete the task, I have to apply my school knowledge.	1.73 (0.704)	2.50 (1.095)	2.20 (0.837)
The task promotes my technical language.	3.20 (0.561)	3.50 (0.632)	3.60 (0.548)
The task promotes my ability to communicate.	2.93 (0.884)	3.06 (0.500)	2.40 (0.894)
The task promotes my ability to explain facts.	3.53 (0.640)	3.63 (0.500)	3.20 (1.095)

Strongly agree = 4; agree = 3; disagree = 2; strongly disagree = 1.

Almost all ratings are in the same range as the ratings from the literature (Hermanns, 2020). The item "promotes my ability to communicate" was rated less well. This can be explained with the setting of the study. Because of the online teaching there was no direct communication between the students (as in the previous studies). Overall, it can be concluded that the students rated the tasks as being relevant for their future profession.

Research question 3: what attitude do pre-service chemistry teachers have towards concepts in organic chemistry?

Eleven students (out of 16) knew anchoring concepts at least partly from their university studies. Almost all students knew these concepts from a course they attended voluntarily in the winter term 2019/20 (name of the course and literature will be added after the reviewing process). However, in other courses anchoring concepts are not explicitly taught and applied as stated by the students. During the focus group interview the students argued that anchoring concepts should be an integral part of the courses in chemistry: *"[they] would be helpful [...] for the own structuring of the content, from new content"*. They also rated concepts as being useful for their future profession and for their own teaching: *"it is for students at school much more motivating, if they recognize a concept in a new context"*.

In the questionnaire (for results see Table 7), the item "concepts in organic chemistry give an opportunity for better understanding the content" was rated between 3.47 till 3.80 (for the three tasks) and therefore between agree and strongly agree. It can therefore be concluded that anchoring concepts should be explicitly taught and applied in university courses in organic chemistry. The rating of the item "the included concepts are important for my future profession" which is rated between 3.40 till 3.62 and therefore also between agree and strongly agree supports this. However, the students are no experts on the use of concepts. The selection of the concepts they needed for the task was rated mostly as being not easy. The arithmetic means for the first two task were 2.27 and 2.88 and therefore in the range of "disagree". For the third task the rating was better, but task 3 was solved only by five students (two in their master studies) who voluntarily agreed to solve another task. Most certainly that was those students that had less problems with the application of concepts. Overall, we hypothesize that the students did not have sufficient opportunity for training the application of concepts when solving tasks.

Research question 4: how do the students rate the usefulness of anchoring concepts for solving tasks?

The students selected the anchoring concepts they used for solving the task and explained their choice. The students' explanations were coded using the method of qualitative content analysis (Kuckartz, 2016). For task 1, the inter coder reliability (Brennan & Prediger, 1981) for the concepts "atoms", "bonds", "structure and function" and "chemical reactions" was 87.9% and therefore sufficient. Table 6 shows the assignment of the answers to the anchoring concepts.

In the students' assessment which anchoring concepts they used for solving the tasks there are some inconsistencies. Although 14 out of 16 students used structural formulas for solving task 1, only 25.0% chose the use of the concept "visualization" for this task. This is surprising because structural formulas are a model to describe what happens on the microscopic level. Because the students used their structural formulas in this way, they should have chosen this concept. This shows that the students don't reflect which concepts they are using, most certainly because the application of concepts while solving tasks is unusual for them. This is supported by their rating that concepts were mostly no explicit part of their university studies. A comparison of the choice of concepts for the three tasks shows that the students used mostly the same concepts: "atoms", "bonds", "structure and function" and "chemical reactions". The other concepts, especially "energy and thermodynamics" and "kinetics" are rated to be less important. The students don't see the link between those concepts and organic chemistry as the following citation from the focus group interview shows: *"I think that the concepts are sufficient for organic chemistry. I think the concepts go beyond organic chemistry, for example*

Table 6: Students' use of anchoring concepts for solving the tasks.

Anchoring concept	Task 1	Task 2	Task 3
Atoms	68.8%	75.0%	80.0%
Bonds	100.0%	100.0%	100.0%
Structure and function	87.5%	87.5%	80.0%
Intermolecular forces	–	–	40.0%
Chemical reactions	87.5%	75.0%	100.0%
Energy and thermodynamics	50.0%	43.8%	20.0%
Kinetics	12.5%	12.5%	40.0%
Chemical equilibrium	–	–	80.0%
Experiments, data	12.5%	18.8%	20.0%
Visualization	25.0%	31.3%	40.0%

aspects as energy and thermodynamics or kinetics. I was a bit confused, because I thought, what does that have to do with organic chemistry?" One reason for this can be that such issues were no part of the courses in organic chemistry. The students would then rate especially those concepts as being useful that they connect with the content of their course. The usefulness of the concepts for solving the tasks was also rated by the students with the questionnaire. Table 7 shows the results.

Table 7: The students' rating of the anchoring concepts.

	Task 1 (N = 15) M (SD)	Task 2 (N = 16) M (SD)	Task 3 (N = 5) M (SD)
The included concepts are important for my future profession.	3.33 (0.816)	3.62 (0.619)	3.40 (0.548)
The selection of the concepts that were used was easy.	2.27 (0.884)	2.88 (0.619)	3.20 (0.837)
The task supports the understanding of anchoring concepts.	2.87 (0.743)	3.25 (0.683)	3.60 (0.548)
The concepts support the solving of the task.	2.60 (0.828)	3.31 (0.479)	3.20 (0.837)
Anchoring concepts of organic chemistry give the chance of better understanding the content.	3.47 (0.516)	3.69 (0.479)	3.80 (0.447)
Concepts in organic chemistry build a bridge between university and school knowledge.	3.21 (0.699)	3.31 (0.704)	3.20 (0.837)

Although the students rate anchoring concepts as being helpful for understanding the content, the rating of the item "the concepts support the solving of the task" was only between 2.60 and 3.31 (disagree till agree). As discussed before it can be assumed that the students did not have sufficient opportunity for applying concepts while solving tasks. This is supported by the rating of the item "the selection of the concepts that were used was easy" because this was for the first two tasks 2.27 and 2.88 (not agree till agree). The rating for the item "the tasks support the understanding of anchoring concepts" was rated slightly better (arithmetic mean between 2.87 and 3.60). Whether the rating of these items changes should be evaluated in the near future in a course where concepts are explicitly taught and applied.

Research question 5: in what way do concepts build a bridge between university and school knowledge as defined by the SRCK-concept?

This research question takes into account that the SRCK is a knowledge category between school knowledge and university knowledge and therefore builds a bridge between those knowledge categories. SRCK-tasks should support the acquisition of this knowledge. Because the SRCK-construct included concepts, these concepts should be support this connection. The item “concepts in organic chemistry build a bridge between university and school knowledge” is rated by the students between 3.20 and 3.31 and therefore with “agree”. This also supports our claim that concepts should be an integral part of courses in organic chemistry. Student 5 says in the focus group interview: *“if you had the concepts in school and you remember them at university, you could build upon them”* and *“if you have a concept at university, you can, because you learned it at university and because it is explicit that it is a concept, you can use it as concept in school or use it to structure lessons at school”*. Student 6 supports this: *“from university down to school it is supporting, because that’s the meaning of concepts to join maybe 80% of the reactions with the concepts”*.

Overall, the students see the potential of concepts as forming a bridge from school knowledge to university knowledge and *vice versa*.

Limitations

There are some limitations to this study. First, the number of students ($N = 16$) was not very high. Due to online-learning in the corona virus pandemic no personal contact with the students was possible. The students were asked to participate by e-mail. Although the students received a small compensation for their time, only 16 students wanted to participate. All contact during the study was online via e-mail. For the focus group interview, six students were invited; five students participated. However, a comparison from the data in this study with data from previous studies showed that the students as a group did not differ significantly from groups with a higher attendance. Therefore, the results of this study give some important insight in the students’ knowledge of concepts and their opinion on the use and application of concepts in teaching and learning organic chemistry.

Conclusions and outlook

Concepts are rated as being useful as for example stated by student 4 in the focus group interview: *“For me concepts help to structure the technical content, especially if the content has been a long time ago […]. At school there are basic concepts that also can be very motivating for students if they recognize concepts that they already know while learning different contents of chemistry”*. For chemistry educators that mean that they should teach concepts explicitly and give their students the opportunity to apply these concepts while solving tasks and reflect on their use. The combination of SRCK-tasks with the application of concepts seems promising, because the students rate both those tasks and the application of concepts as relevant for their future. For our bachelor course on “organic chemistry” we will redesign the course with a clear focus on anchoring concepts and their application. The course design will not follow functional groups, but will start with bonding, structural formulas, concepts as the acid-base-, redox- and electrophile-nucleophile-concept, reaction mechanisms and then the application of these concepts on examples from several chemical families. To connect topics and concepts from general chemistry with organic chemistry, the anchoring concepts will be included explicitly in this new course, for example by asking students which concepts they used for solving a task and discussing their selection during the seminar. Tasks designed following the SRCK-concept should also be part of this new course, because the students rate these tasks as relevant for their future profession and as useful for training basic skills on communication.

Supplementary Material

The tasks used in the study.

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References

Allen, E., & Seaman, C. (2007). Likert scales and date analyses. *Quality Progress*, *7*, 64–65.

Atkins, P. (1999). Chemistry: The great ideas. *Pure and Applied Chemistry*, *71*, 927–929.

Ball, D. L., Thames, M. H., & Phelphs, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education*, *59*, 389–407.

Brennan, R. L., & Prediger, D. J. (1981). Coefficient Kappa: Some uses, misuses, and alternatives. *Educational and Psychological Measurement*, *41*, 687–699.

Cooper, M. M., Posey, L. A., & Underwood, S. M. (2017). Core ideas and topics: Building up or drilling down? *Journal of Chemical Education*, *94*(5), 541–548.

Grove, N. P., & Bretz, S. L. (2012). A continuum of learning: From rote memorization to meaningful learning in organic chemistry. *Chemistry Education: Research and Practice*, *13*, 201–208.

Hermanns, J. (2019). Erweitertes Fachwissen für den schulischen Kontext – Konzeption und Evaluation von Aufgaben zur Vorlesung „Organische Experimentalchemie I" [SRCK – concept and evaluation of tasks for the lecture „organic chemistry I"]. *CHEMKON*, *26*(1), 31–35.

Hermanns, J. (2020). Perceived relevance of tasks in organic chemistry by preservice chemistry teachers. *Chemistry Teacher International*. https://doi.org/10.1515/cti-2020-0002.

Hermanns, J., & Thomanek, O. (2020). A Delphi study on the school-related content knowledge in organic chemistry. *RISTAL*, *3*, 146–165.

Kuckartz, U. (2016). *Qualitative Inhaltsanalyse. Methoden, Praxis, Computerunterstützung. [Qualitative content analysis. Methods, practice, computer assistance]*. Weinheim and Basel, Germany and Switzerland: Beltz.

Massolt, J., & Borowski, A. (2018). Increasing the perceived relevance of university physics problems by focusing on school-related content knowledge. *heiEDUCATION Journal*, (1/2), 99–122.

Massolt, J., & Borowski, A. (2020). Perceived relevance of university physics problems by pre-service physics teachers: Personal constructs. *International Journal of Science Education*, *42*(2), 167–189.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington: National Academies Press.

Raker, J., Holme, T., & Murphy, K. (2013). The ACS Exams Institute undergraduate chemistry anchoring concepts content map II: Organic chemistry. *Journal of Chemical Education*, *90*(11), 1443–1445.

Riese, J. (2009). *Professionelles Wissen und professionelle Handlungskompetenz von (angehenden) Physiklehrkräften. [Professional knowledge and competence of action of (prospective) physics teachers]*. Berlin: Logos.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14.

Woehlecke, S., Massolt, J., Goral, J., Hassan-Yavuz, S., Seider, J., Borowski, A., & Glowinski, I. (2017). Das erweiterte Fachwissen für den schulischen Kontext als fachübergreifendes Konstrukt und die Anwendung im universitären Lehramtsstudium. [School-related content knowledge as multidisciplinary construct and its application in the academic teacher training]. *Beiträge zur Lehrerinnen- und Lehrerbildung*, *35*(3), 413–426.

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