Institut für Physik und Astronomie
Lehrstuhl Didaktik der Physik

# Perceived Relevance of Physics Problems

## *by pre-service physics teachers*

Dissertation

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# 1 Introduction

## 1.1 (The Problem with) Physics Teacher Education in Germany

Germany has an increasing physics teacher shortage (Klemm, 2015), a problem that is also seen in some other european countries (European Commission, 2013). The lack of learning motivation of pre-service physics teachers can be seen as part of the problem (Heublein et al., 2017; Albrecht, 2011). To understand this, one first has to know how the teacher training system in Germany is set up. In Germany, pre-service teachers study two subjects and they are (almost) fully free to choose any combination of subjects. The typical combination physics and mathematics is possible, but also a combination like physics and history (see also Viebahn, 2003) can be chosen. Their Bachelor of Education includes content knowledge and pedagogical content knowledge courses in the two subjects together with general pedagogical knowledge courses. The content knowledge courses in physics are often offered for both the pre-service physics teachers as well as the physics major students combined (DPG, 2010). These courses are however tailored for the latter group. A reason for this can be the belief that the content knowledge courses for pre-service teachers should be closely related to that of future physicist (Großmann, 2002), but often the two groups are also put together because of budgetary reasons. The combination of the two groups in the same courses can be seen as one of the causes that leads to the problem that is central to this dissertation: pre-service physics teachers often have difficulties seeing the connection between the content taught in these courses and the content knowledge they need in their future career as physics teachers. To quote one of the students: “Of course teachers should know more than their students, but they teach us so much content knowledge that has no relevance for school students” (AG Studienqualität, 2011, translation by author). They feel that the physics content taught at university does not meet their needs (Merzyn, 2004). The pre-service physics teachers wish for a more pronounced connection between the content knowledge courses and the pedagogical content knowledge courses and more school-relevant content (Bergau et al., 2013; Riese, 2009). The problem seems to be one of perceived relevance: the students do not see the content taught at university as relevant for school. The word 'perceived' is important here. The content taught at university might actually be relevant for their later profession. If the students do not however *perceive* the content as relevant, the effect on the students is the same as with content that would actually be irrelevant to them.

This is not only a problem in physics or only a German problem: Koponen et al. (2016) describe the same problem for mathematics pre-service teachers in Finland. In mathematics the problem even seems to be more severe. The transitions from school mathematics to university mathematics and - after obtaining their teaching certificate - from university mathematics back to school mathematics is described as a 'double discontinuity' (Klein, 1908): this double transition is very demanding for the students, they do not see the relevance of the university mathematics because it is so completely different from the school mathematics. In general, the school subjects have "a ‚life of their own' with their own logic; that is, the meaning of the concept taught cannot be explained simply from the logic of the respective scientific discipline"(Bromme, 1994, p74). Although the transition from university physics to school physics is maybe not as challenging in physics, there are still differences between the physics in school and physics as a science (Deng, 2007) which can be seen as one of the reasons that students have difficulties seeing the relevance of university physics.

## 1.2 Relevance and Motivation

Why is this a problem? The perceived relevance of a course is linked to the motivation of the students in it. The motivational appeal of courses has been described by Keller (1983). In his ARCS model (Attention, Relevance, Confidence and Satisfaction, Keller, 1984), relevance is one of the conditions for a motivating course. Keller describes relevance here as the perception of a student of whether the course instruction or content satisfies their personal needs. A personal connection is also described by Priniski et al. (2018). In their framework - based on i.a. Hidi and Renninger (2006); Eccles et al. (1983); Deci and Ryan (1985) - they define relevance as a 'personally meaningful connection to the individual' and conceptualize relevance on a continuum of personal meaningfulness, from a 'personal association level' to 'identification'.

The link between a lower perceived relevance and a lower learning motivation (e.g. Keller, 2010; Frymier and Shulman, 1995; Kember et al., 2008; Sass, 1989; Weaver and Cottrell, 1988) causes a problem: a lower perceived relevance (and therefore a lower learning motivation) is one of many reasons for students to discontinue their study (Albrecht, 2011; Heublein et al., 2017). Besides this quantitative problem (a lower perceived relevance leads to less teachers), a lower perceived relevance can also lead to qualitative problems (a lower perceived relevance leads to teachers with a lower level of physics content knowledge) since it is linked to lower academic achievement and a worse retention of knowledge (e.g. Harris et al., 2003; Malau-Aduli et al., 2013; Petty and Cacioppo, 1981, 1986; Schiefele et al., 2003). For a further description of (the connection between) perceived relevance and motivation, see sections 2.2 and 2.3.

## 1.3 Goals of this Study

As described above, it makes sense to increase the perceived relevance of courses. It should lead to less drop-out by taking away one of the reasons for study discontinuation and to teachers with a higher level of content knowledge by increasing their study motivation. The goal of the intervention described in this dissertation is to increase the perceived relevance of physics content knowledge courses aimed at both physics major students and pre-service physics students.

### 1.3.1 The PSI-Potsdam Project

The project is part of a focus group of the 'Qualitätsoffensive Lehrerbildung' (see Frister (2018) for a description of this overarching program) project 'PSI-Potsdam' (*Professionalisierung, Schulpraktische Studien, Inklusion [Professionalization – School-Placement-Studies – Inclusion]*). This group focuses on the improvement of the professional knowledge of pre-service teachers through two approaches: (1) by interconnecting the content knowledge and professional content knowledge courses of the teacher training in Potsdam and (2) by making the content knowledge courses more relevant for the pre-service teachers. This study is set in the focus group 'Professionalisierung'. For a description of this focus group, see Glowinski (2015).

### 1.3.2 Experimental Physics

The goal of the intervention described in this dissertation can be specified as follows: to increase the increased relevance - by pre-service physics teachers - of problem sets part of the first and second semester content knowledge courses 'Experimentalphysik 1' and 'Experimentalphysik 2', discussed in tutorial groups with students from both the group of pre-service teachers and the physics major students.

These problem sets are handed out every week, solved at home and then discussed in tutorial sessions led by an instructor. The problem sets can be seen as a very important preparation for the final exam; this importance is demonstrated by making it mandatory for the students to show that they have worked on most of the problems before being able to register for the final exam.

The courses focus on the basics of physics, often repeating content that was taught in secondary school. A reason for this repetition is, next to the benefit of the activation of previous knowledge, the fact that the instructors cannot assume that the students in their class actually enrolled in an advanced physics class in secondary school. It is technically possible that students enrol in the physics education program without having taken physics as a subject in the last two years in secondary school. Experimentalphysik 1 mainly covers the topics dynamics, statics and kinematics; Experimentalphysik 2 covers electrostatics, electrodynamics, magnetism and optics.

### 1.3.3 Increasing Perceived Relevance

But how can the perceived relevance of these problem sets be increased? In his ARCS model, Keller (1983) mentions relevance as an important condition for motivational materials - for instance problem sets. However, he does not describe how a higher perceived relevance can be achieved. The same goes for Kember et al. (2008): relevance is seen as an important property of a motivational course, but it is not clear how the perceived relevance can be increased. Frymier and Shulman (1995) find that relevance influences motivation, but they have difficulties developing a method that sufficiently changes the relevance in an experimental design (Frymier and Houser, 1998).

There are only a few studies that describe an intervention in which the perceived relevance of university course content is increased. Walkington and Bernacki (2014) suggest a 'personalised learning experience' as one of the possible factors that can increase perceived relevance. It should lead to more personally meaningful types of relevance. It is however unclear what this more personalised learning experience would mean in the context of this project. A link between course content and the personal or professional goals of students, as done by Owen (2017), is also an option to increase the perceived relevance. In a research methods course, the content was perceived as more relevant when a connection to a possible later professional application was made. This approach, where an explicit connection between content and later profession was made, is difficult to take in the context of this project: because of an explicit connection to the teacher profession, the increased perceived relevance for pre-service teachers would maybe lead to a decreased perceived relevance by the physics major students. The approach taken should not have negative consequences for one of the groups of the course.

The approach taken by Bauer and Partheil (2009) and Leufer and Prediger (2007) is specifically aimed at pre-service (mathematics) teachers. They designed modules for pre-service teachers that try to bridge the gap between the content knowledge of university mathematics courses and the later professional career of the students. To describe their approach, it is first important to take a side-step and describe the professional knowledge of teachers. The professional knowledge of teachers can be divided into three different knowledge areas: content knowledge (CK), pedagogical content knowledge (PCK) and pedagogical knowledge (PK) (Shulman, 1986; Baumert and Kunter, 2006). These areas are also reflected in the different courses for pre-service teachers in Germany (see section 1.1). Content knowledge is seen as a basic prerequisite for good teaching. It is a prerequisite for - and influences - the acquisition of pedagogical content knowledge (Baumert et al., 2010; Krauss et al., 2008; Terhart, 2002). This second knowledge area, PCK, is described as the 'subject matter knowledge for teaching' (Shulman, 1986, p19) and includes,

among other things, knowledge about 'the ways of representing and formulating the subject that make it comprehensible to others' (Shulman, 1986, p19). For a further overview of the research on PCK, we refer the reader to Hume et al. (2019). Bauer and Partheil (2009) and Leufer and Prediger (2007) connect the content knowledge taught with this knowledge for teaching, PCK. The results, although only studied with a single evaluation after the course, look promising from a motivational standpoint: the students seem to appreciate the material more and perceive it as more relevant.
This connection of CK with PCK seems to work, but is not possible for the study described in this dissertation: the courses Experimentalphysik 1 and Experimentalphysik 2 are pure content knowledge courses: they focus only on physics and not on teaching physics. The instructors usually have no background in PCK: they have no advanced knowledge on how to teach physics in secondary school, so it would be difficult for them to connect CK and PCK in their classes. Offering a supplementary course to only the pre-service teachers - in order to make the connection only for them - is also not practical: there simply are no available credits in the curriculum for any additional course for these students (DPG, 2014).

In an approach by Lorentzen et al. (2019), students of a university physical chemistry course for pre-service chemistry teachers were supported to cross-link the content knowledge of that course with the school-related content knowledge, the knowledge category that describes the teacher-specific content knowledge. Compared to a control group, they found that the intervention showed a positive effect on the perceived relevance of the content knowledge of the course. In a somewhat different approach within in the same course (Stäcker et al., 2018), they developed learning opportunities where the pre-service teachers had to reduce a content analysis for teaching purposes (with the help of knowledge maps) of an everyday phenomenon. They also found positive effects on the perceived relevance by the students. Even though they stayed within the knowledge area CK, both approaches were however only aimed at pre-service (chemistry) teachers and not at the whole group including the chemistry major students.

### 1.3.4 The Approach in this Project

Within the project that is central to this dissertation, a similar approach as the one described by Lorentzen et al. (Lorentzen et al., 2019; Stäcker et al., 2018) is used: an approach where the emphasis is on the teacher-specific content knowledge.

For the CK area, three different categories have been proposed (e.g. Riese (2009); Woitkowski et al. (2011); Riese et al. (2015), see Woitkowski and Borowski (2017) for an overview): school knowledge (containing content from school curricula), university content knowledge (containing content that is required for passing university exams (Riese et al., 2015) and a third category that describes the content knowledge that is specific to teachers. This content knowledge category describes knowledge that is necessary for a deeper understanding of school-relevant content, it is characteristic for networked knowledge which is the basis for the 'explanational repertoire' of a teacher (Baumert and Kunter, 2006) and prepares for the preparation, implementation and analysis of lessons. This content knowledge category connects school knowledge with university knowledge.

Physics problems based on the teacher-specific content knowledge are developed and used alongside regular physics problems. Since the new problems draw on the content knowledge category that is specific for teachers and connect the school knowledge with the university content knowledge, the problems can be seen as more relevant to them. This should lead to an increase in the perceived relevance of the content knowledge that is central to the problem described in the problem sets. Connecting the two content knowledge dimensions can also be of benefit to the physics major students: a deeper understanding of the content of the two courses will be useful for them too. The absence of the direct connection with teaching (the knowledge area PCK is not used in the problems, only CK) also ensures that these students do not have the feeling that these problems are only made for the pre-service teachers.

## 1.4 This Dissertation

This dissertation consists of three papers (See section 2).

### 1.4.1 Paper 1: SRCK

In the first paper (Woehlecke et al. (2017), with the author of this dissertation as shared first author - see section 2.1), the development of the teacher-specific content knowledge category is described. This category, called school-related content knowledge (SRCK)[1], is developed as a cross-disciplinary construct (at least for the subjects physics, mathematics, biology, history and economics-labor-technology) on the basis of subject-specific predecessors (Ball et al., 2008; Heinze et al., 2016; Loch, 2015; Riese et al., 2015; Woitkowski et al., 2011). Other than the previous descriptions, it takes both the substantive (knowledge *of* the discipline) and syntactic structures (knowledge *about* the discipline) of content knowledge into account (e.g. Anderson and Clark, 2012; Ball, 1990; Hodson, 2009; Schwab, 1964, 1978; Shulman, 1986, 1987). The three facets in this construct (knowledge about concepts and their application in the respective subject, knowledge to adapt complexity meaningfully and anticipatorily and knowledge about subject-specific knowledge processes including theories, terminology and epistemological and validity principals) describe the knowledge and abilities that are necessary for a deeper understanding of the content knowledge in the school curriculum. Possible application of SRCK are also described in this paper.

### 1.4.2 Paper 2: Intervention Study

Central to this dissertation is the second paper (Massolt and Borowski, 2018, see section 2.2). An intervention study over two semesters in the courses Experi-

[1] In German: *das erweiterte Fachwissen für den schulischen Kontext*

mentalphysik 1 and 2 is described in this paper. Physics problems based on the facets of SRCK are developed and introduced in weekly problem sets discussed in tutorial groups for these courses. These problems are conceptual problems that have school relevance because they connect school knowledge with university knowledge. These problems are used alongside conceptual problems that are not based on the facets of SRCK (and are therefore not explicitly school relevant) and regular, quantitative problems (which are also not explicitly school relevant). Students were asked to rate all the problems with regards to perceived relevance at the start of every tutorial session. To find out whether a possible difference in perceived relevance is due to the possible difference in difficulty of the different problem types, they were also asked to rate the problems with respect to difficulty. The outcome of this study is that when the content of the problems is more distant to the content discussed in school, both conceptual problem types are perceived as more relevant by the pre-service teachers than the regular, quantitative problems. The study was done with both the pre-service teachers and the physics major students. This was done to avoid giving the pre-service teachers the idea that there was an intervention made specifically for them and thereby influencing their results, but also to find out whether the newly introduced problems were seen as more or less relevant by the physics major students. No effect could be found with this latter group of students.

### 1.4.3 Paper 3: Interview Study

The third paper (see section 2.3, Massolt and Borowski, 2020) builds upon the results of the second paper. Apparently, the conceptual problems that are based on SRCK are perceived as just as relevant as the conceptual problems that are not based on SRCK. The problem property 'conceptual problem' seems to make the problem more relevant to the pre-service teachers. Are there other problem properties that have an influence on the perceived relevance? How do students determine whether or not a problem is relevant to them? To explore this, an interview study with $N = 7$ students was conducted. Nine problems (three from every problem type) were discussed with these students. First they were asked to rate all the problems with respect to perceived relevance. Then three problems were taken into consideration. They were asked to distinguish these three problems from each other: what makes two of these problems different from the other? This interview technique - the repertory grid technique (e.g. Fromm, 1995; Hillier, 1998; Jankowicz, 2004), based on the personal construct theory (Kelly, 1955) - allows the interviewer to capture the subjective views of the students. Their implicit knowledge can be described, or their 'gut feeling' or intuition (Haldin-Herrgard, 2004). With this technique, six problem properties were identified that have a positive effect on the perceived relevance by pre-service physics teachers.

# 2 Manuscripts

## 2.1 Das erweiterte Fachwissen für den schulischen Kontext als fachübergreifendes Konstrukt und die Anwendung im universitären Lehramtsstudium

This paper - in English 'the cross-disciplinary construct of school-related content knowledge and its application in initial teacher education' - is published in the journal 'Beiträge zur Lehrerinnen- und Lehrerbildung'. The paper was mainly written by Sandra Woehlecke and the author of this dissertation, with the help of the other authors.
Although Sandra Woehlecke is mentioned first in the list of authors, the first two authors did equal amounts of work on this paper and can both be seen as first authors. This is also mentioned in the footnote on the title page of the paper: *Die Autorin und der Autor haben im Sinne einer geteilten Erstautorenschaft gleichermassen zur Entstehung des Manuskripts beigetragen. [In the sense of a shared first authorship, the authors [referred to with an asterisk] have contributed equally to the creation of the manuscript.]*

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# Das erweiterte Fachwissen für den schulischen Kontext als fachübergreifendes Konstrukt und die Anwendung im universitären Lehramtsstudium

*Beiträge zur Lehrerinnen- und Lehrerbildung 35 (2017) 3, S. 413-426*

BEITRÄGE ZUR LEHRERINNEN- UND LEHRERBILDUNG, 35 (3), 2017

# Das erweiterte Fachwissen für den schulischen Kontext als fachübergreifendes Konstrukt und die Anwendung im universitären Lehramtsstudium

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**Zusammenfassung** Basierend auf theoretischen Vorarbeiten und Definitionsansätzen zum Professionswissen von (angehenden) Lehrkräften wird im Beitrag eine fachübergreifende Konzeptualisierung und Operationalisierung des berufsspezifischen Fachwissens vorgestellt: Das erweiterte Fachwissen für den schulischen Kontext beschreibt konzeptuelles Wissen und Fähigkeiten, welche zum tieferen Verständnis schulrelevanter Inhalte nötig sind. Es meint ein (Meta-)Wissen auf der Basis von universitärem Wissen, das dessen fachliche Anwendung und Bedeutung im Kontext von Schulwissen betrifft. Zudem werden zwei Vorschläge für Lerngelegenheiten zum Erwerb des erweiterten Fachwissens im universitären Lehramtsstudium dargestellt.

**Schlagwörter** Professionswissen – Fachwissen – erweitertes Fachwissen für den schulischen Kontext – Lehramtsstudium

## The cross-disciplinary construct of school-related content knowledge and its application in initial teacher education

**Abstract** Based on theoretical groundwork and definitions concerning the professional knowledge of (prospective) teachers, we present a cross-disciplinary approach to conceptualizing and operationalizing teaching-specific content knowledge. So-called school-related content knowledge consists of conceptual knowledge and skills that are necessary for a thorough understanding of contents relevant to school teaching. It refers to meta-knowledge that rests on academic knowledge and both its application and meaning as regards the knowledge to be imparted at school. Furthermore, we outline two suggestions for creating learning opportunities for acquiring school-related content knowledge in teacher preparation programs.

**Keywords** professional knowledge – content knowledge – school-related content knowledge – initial teacher education

* Die Autorin und der Autor haben im Sinne einer geteilten Erstautorenschaft gleichermassen zur Entstehung des Manuskripts beigetragen.

## 1 Einleitung

Es steht ausser Frage, dass für einen sach- und fachgerechten Unterricht ein «fundiertes und anschlussfähiges» Fachwissen obligatorisch ist (Kultusministerkonferenz, 2008, S. 19). Eine Herausforderung stellt sich jedoch bei der fachspezifischen Ausdifferenzierung dieses fachwissenschaftlichen Wissens und bei der Konzeption entsprechender Lerngelegenheiten innerhalb des Studiums angehender Lehrkräfte. Bereits Klein (1908) beschrieb mit dem Begriff «Doppelte Diskontinuität» die von Lehramtsstudierenden wahrgenommenen Brüche hinsichtlich der Inhalte und Ziele der Mathematik sowohl beim Übergang von der Schule zur Universität als auch beim Übergang von der Universität zur Schule als Lehrkraft. Es ist jedoch ungeklärt, ob sich diese Problematik auf andere Fächer übertragen lässt (Deng, 2007). Auch Bromme (1994) nimmt eine unterschiedliche Logik von Schulfach und zugehöriger Disziplin an.

Das fachwissenschaftliche universitäre Studium der Lehramtsstudierenden in Deutschland ist geprägt von einer Ausrichtung an der entsprechenden akademischen Disziplin. An vielen Hochschulen studieren angehende (Gymnasial-)Lehrkräfte, zumindest im fachwissenschaftlichen Studium, gemeinsam mit Fachstudierenden. Fachliche Lehrveranstaltungen, die ausschliesslich für Lehramtsstudierende konzipiert sind, sind eher selten (Centrum für Hochschulentwicklung, 2016). Diese Situation kann auf kapazitären Gegebenheiten der Universitäten beruhen, aber auch auf der Überzeugung, dass sich die fachwissenschaftliche Ausbildung der Lehramtsstudierenden eng an derjenigen der zukünftigen Fachwissenschaftlerinnen und Fachwissenschaftler orientieren sollte (z.B. Grossmann, 2002). Aufgrund der Neustrukturierung des Lehramtsstudiums an vielen deutschen Universitäten, u.a. zugunsten der Qualifizierung im inklusionspädagogischen Bereich, stehen im Allgemeinen weniger Leistungspunkte für die fachwissenschaftliche Ausbildung zur Verfügung (Centrum für Hochschulentwicklung, 2016). Neben der Frage des Umfangs stellt sich die Frage der sinnvollen Auswahl fachwissenschaftlicher Inhalte für das Lehramtsstudium. An vielen deutschen Universitäten empfindet ein Grossteil der Studierenden die fachwissenschaftliche Ausbildung als überbetont im Vergleich zur fachdidaktischen Ausbildung (AG Studienqualität, 2011; Riese, 2009). Die Studierenden geben zusätzlich eine mangelhafte Vorbereitung auf die Berufspraxis an (Mischau & Blunck, 2006). Dass diese Problematik auch internationale Relevanz aufweist, zeigen Koponen, Asikainen, Viholainen und Hirvonen (2016). Gerade für das fachwissenschaftliche Professionswissen von Lehrkräften kann jedoch angenommen werden, dass die universitären Lerngelegenheiten eine sehr hohe Relevanz haben (Borowski, Kirschner, Liedtke & Fischer, 2011; Kleickmann et al., 2013).

In der Forschung zum Professionswissen von (angehenden) Lehrkräften wird davon ausgegangen, dass sich das Fachwissen in verschiedene Kategorien/Niveaustufen differenzieren lässt (u.a. Ball, Thames & Phelps, 2008; Riese, 2009). Es wurde ein berufsspezifisches Fachwissen für die Physik (Kirschner, 2013; Riese, 2009; Riese et al., 2015; Woitkowski, Riese & Reinhold, 2011) bzw. für die Mathematik (Ball et al., 2008;

Loch, 2015) modelliert, u.a. «vertieftes Schulwissen» oder «Fachwissen im schulischen Kontext» genannt, das als besonders relevant für Lehrkräfte gilt. Im Folgenden wird ausgeführt, wie ein solches berufsspezifisches Fachwissen für Lehrpersonen im Projekt PSI-Potsdam[1] («Professionalisierung – Schulpraktische Studien – Inklusion») fachübergreifend konzipiert werden kann. Theoretische Vorannahmen und normative Setzungen zum Professionswissen von Lehrkräften und Wissensrepräsentationen sind dabei leitend. Zwei Möglichkeiten werden vorgestellt, die aufzeigen, wie das von uns so benannte «erweiterte Fachwissen für den schulischen Kontext» als Grundlage für die Konzeption von fachwissenschaftlichen Lehrveranstaltungen und von Fachdidaktik und Fachwissenschaft integrierenden Lehrveranstaltungen fungieren kann.

## 2 Das Fachwissen von Lehramtsstudierenden

Seit der Mitte der 1980er-Jahre ist bei der Suche nach der «guten» Lehrkraft das Expertenparadigma in den Mittelpunkt des Interesses gerückt. Für das Professionswissen von Lehrkräften hat Shulman (1986, 1987) eine umfassende, theoretisch abgeleitete Taxonomie vorgelegt, die alle Aspekte des Professionswissens von Lehrkräften umfasst und nach Bromme (2008) dem wissenszentrierten Expertiseansatz zugeordnet werden kann. Diese wurden im Kompetenzmodell von COACTIV aufgegriffen und um nicht kognitive Kompetenzaspekte ergänzt (Krauss, 2011). Shulman (1986) grenzte in seiner Taxonomie «content knowledge» bzw. «subject matter knowledge» von «pedagogical content knowledge» und «pedagogical knowledge» ab. Hinsichtlich des fachwissenschaftlichen Wissens der Lehrkräfte unterscheidet Shulman (1986) in Anlehnung an Schwab (1964, 1978) innerhalb des «content knowledge» eine «substantive structure» von einer «syntactic structure». Unter «substantive structure» wird dabei das Wissen über bedeutende Schlüsselaspekte und Konzepte einer Disziplin sowie deren Zusammenhang verstanden (Ball, 1990; Hashweh, 2005), darüber hinaus aber auch der Erklärungsrahmen, der diese Kernthemen organisiert und verbindet (Windschitl, 2004). Mit «syntactic structure» sind hingegen das Wissen hinsichtlich der Methoden und der Evidenzkriterien sowie das Wissen über die Generierung des Wissens innerhalb der Disziplin und die Methoden der Erkenntnisgewinnung in der Disziplin gemeint (Anderson & Clark, 2012; Hodson, 2009). Kurz gefasst können diese beiden Kategorien auch als «Wissen in der Disziplin» bzw. «Wissen über die Disziplin» charakterisiert werden (Ball, 1990). Windschitl (2004) stimmt weitgehend mit der Konzeption von «syntactic knowledge» überein, spricht jedoch von «disciplinary knowledge» und beschreibt darunter z.B. den Aspekt «knowledge of domain-specific methods of investigation». Dabei ist ein Wissen über die Erkenntnisgewinnung in der Disziplin weni-

[1] Das diesem Bericht zugrunde liegende Vorhaben wurde im Rahmen der gemeinsamen «Qualitätsoffensive Lehrerbildung» von Bund und Ländern mit Mitteln des Bundesministeriums für Bildung und Foschung unter dem Förderkennzeichen 01JA1516 gefördert. Die Verantwortung für den Inhalt dieser Veröffentlichung liegt bei den Autorinnen und Autoren.

ger mit einem prozeduralen Wissen gleichzusetzen. Vielmehr werden damit epistemologische Aspekte umschrieben sowie Aspekte, die auch in den Konzepten «Nature of Science» (Lederman, 1992) oder «Nature of History» (Günther-Arndt, 2006) aufgehen. Anderson und Clark (2012) sehen für die Naturwissenschaften eine weitgehende Überschneidung zwischen «Nature of Science» und «syntactic knowledge»; empirisch ist dies jedoch bislang ungeklärt.

Ball et al. (2008) unternahmen ebenfalls eine weitere Spezifizierung des Fachwissens auf der Basis von Shulman (1986) und Schwab (1964, 1978). Sie identifizierten bei ihren Konzeptualisierungen des fachdidaktischen Wissens und bei der Abgrenzung dieses Wissens vom fachwissenschaftlichen Wissen einen Anteil, der eindeutig dem Fachwissen zugerechnet werden kann und gleichzeitig notwendig ist für erfolgreiches Unterrichten. Diese Komponente fachwissenschaftlichen Wissens wird von ihnen als «specialized content knowledge» (SCK) bezeichnet und folgendermassen charakterisiert: «[SCK] is the mathematical knowledge and skill unique to teaching ... [It] involves an uncanny kind of unpacking of mathematics that is not needed – or even desirable – in settings other than teaching» (Ball et al., 2008, S. 400). Hierunter fällt z.B. die Analyse von fachlich falschen Rechenschritten oder die Prüfung der Generalisierbarkeit unüblicher, aber im Einzelfall korrekter Rechenverfahren. Sie grenzen SCK von «common content knowledge» ab. Darunter verstehen die Autorin und die Autoren ein mathematisches Wissen, das der mathematikspezifischen Ausbildung entspricht und über das alle verfügen, die sich mit entsprechenden mathematischen Problemlöseprozessen und mathematischen Sachverhalten beschäftigen.

Hinsichtlich der Operationalisierung des fachwissenschaftlichen Wissens sind in den grösseren nationalen empirischen Studien zur Erhebung des Professionswissens verschiedene Ansätze umgesetzt worden. Die oben dargelegten konzeptuellen Ansätze sind in dieser Differenziertheit allerdings bisher überwiegend nicht berücksichtigt worden. Weitgehend wurde bisher auf «substantive knowledge» fokussiert.

## 3 Forschungsstand zum berufsspezifischen Teil des Fachwissens von (angehenden) Lehrkräften

Im Folgenden wird aufgezeigt, wie in bisherigen Studien das Fachwissen von (angehenden) Lehrkräften differenziert und operationalisiert wurde. Grundsätzlich zeigen sich zwei verschiedene Arten bei der Differenzierung: erstens eine Differenzierung nach Niveaustufen bzw. Fachstufen und zweitens eine Differenzierung mit Berücksichtigung einer berufsspezifischen Kategorie, wobei nicht ausschliesslich einer Stufung gefolgt wird.

Eine Ausdifferenzierung des Fachwissens zeigt sich z.B. im Projekt COACTIV (Baumert & Kunter, 2006). Das Fachwissen wird hier in vier Ebenen unterteilt: «1. Mathematisches Alltagswissen ...; 2. Beherrschung des Schulstoffs ...; 3. Tieferes Verständnis der Fachinhalte des Curriculums der Sekundarstufe ...; 4. Reines Universitätswissen ...» (Krauss et al., 2008, S. 237). In der Studie selbst wurde nur auf der dritten Ebene Fachwissen erhoben. In der MT21-Studie (Blömeke, Kaiser & Lehmann, 2008) ist eine ähnliche Differenzierung zu erkennen. Studien zum Fachwissen von (angehenden) Physiklehrkräften (Riese, 2009; Riese et al., 2015; Woitkowski et al., 2011) differenzieren das Fachwissen in die voneinander abgrenzbaren Niveaustufen «Schulwissen», «vertieftes (Schul-)Wissen» und «universitäres Wissen». Riese (2009, S. 80) beschreibt das vertiefte Wissen u.a. als «vertieftes und vernetztes Wissen in Bezug auf den Schulstoff; Schulphysik von einem höheren Standpunkt aus». Die hier verwendete Binnenstruktur des Fachwissens konnte mit konfirmatorischen Faktorenanalysen bestätigt werden (Riese, 2009). Das rein universitäre Wissen klärt, im Gegensatz zu den zwei anderen Niveaustufen, das fachdidaktische Wissen nur zu einem geringen Teil auf. Es zeigen sich jedoch positive Zusammenhänge zwischen dem universitären Wissen und dem vertieften Schulwissen. Universitäres Wissen ist also nicht irrelevant, aber das Schulwissen und das vertiefte Wissen scheinen für das Handeln im Kontext von Physikunterricht unmittelbar bedeutender zu sein (Riese, 2009). Weil Riese in den Aufgaben zu diesen Niveaustufen keinen steigenden Schwierigkeitsgrad nachweisen konnte, verwenden Woitkowski et al. (2011) statt des Begriffs «Niveaustufen» den Begriff «Fach-Stufen». Das vertiefte Wissen wird hier umschrieben als Wissen, das die Brücke schlägt zwischen Schulwissen und universitärem Wissen. Einige Charakteristika des vertieften Wissens sind beispielsweise «explizite Kombination von Schul- und universitärem Wissen», «Reflexion von Bedeutung, Genese und Verwendung von Begriffen der Schulphysik» oder «Erkennen von Fehlvorstellungen». Im Rahmen des Projekts Profile-P (Riese et al., 2015) wird das vertiefte Schulwissen als Orientierung zur Erstellung von Testitems u.a. mit den folgenden Fähigkeiten modelliert: «Verschiedene Wege zur Lösung einer Aufgabe identifizieren und anwenden» und «Randbedingungen einer Schulaufgabe erkennen».

Als Studien, die eine berufsspezifische Kategorie des Fachwissens modellieren und operationalisieren, sind im internationalen Bereich vor allem die oben beschriebenen Arbeiten der Michigan-Group zu nennen (u.a. Ball et al., 2008). Analysen deuten an, dass eine Multidimensionalität plausibel ist (Hill, Schilling & Ball, 2004). Darauf aufbauend beschreibt Loch (2015) im Rahmen der KiL-Studie (Mathematik) eine Komponente des fachspezifischen Wissens von Lehramtsstudierenden: das Fachwissen im schulischen Kontext (FWsK). Es wird gezeigt, dass ein dreidimensionales Modell (bestehend aus akademischem Fachwissen, FWsK und fachdidaktischem Wissen) die Struktur der erhobenen Daten am besten widerspiegelt. Das FWsK ist vom akademischen Fachwissen und fachdidaktischen Wissen empirisch trennbar (Heinze, Dreher, Lindmeier & Niemand, 2016; Loch, 2015). Das FWsK wird in drei Facetten unterteilt: (1) Das «Wissen über Zusammenhänge zur Hintergrundtheorie» stellt eine Art «Verknüpfungswissen» (Loch, 2015, S. 53) zwischen dem akademischen Fachwissen und dem Schulwissen dar. (2) Die Facette «Wissen über fachliche Folgen von Reduktionen» umfasst «Kenntnisse darüber, welche mathematischen Ungenauigkeiten, ... in didaktisch aufbereiteten Unterrichtsmaterialien entstehen können und welche Auswirkungen dies auf darauf aufbauende Themenbereiche des Unterrichts haben kann» (Loch, 2015, S. 53). (3) Zuletzt beschreibt das «Curriculare Wissen» die «Kenntnisse über die curriculare Anordnung von Inhalten aufgrund der mathematischen Struktur und der … Abhängigkeit eines Inhalts von einem anderen» (Loch, 2015, S. 54).

## 4 Facetten des erweiterten Fachwissens für den schulischen Kontext im Projekt PSI-Potsdam

Ausgehend von den beschriebenen Studien und theoretischen Arbeiten, die das erweiterte Fachwissen[2] und verwandte Konstrukte fachspezifisch in den Blick nehmen, wurde im Projekt PSI-Potsdam das Konstrukt «erweitertes Fachwissen für den schulischen Kontext» erstellt, welches, ebenso wie in den Projekten FALKO (Krauss et al., 2017) und ProwiN (Borowski et al., 2010), den Anspruch einer fachübergreifenden Gültigkeit erhebt und mindestens für die im Projekt PSI beteiligten Fächer Biologie, Geschichte, Mathematik, Physik und Wirtschaft-Arbeit-Technik (WAT) Passung zeigt. Das erweiterte Fachwissen wird von den anderen Kategorien des Fachwissens, d.h. hier Schulwissen und universitäres Wissen, abgegrenzt (vgl. Abbildung 1). In diesem Sinne folgen wir den Modellen von Riese (2009), ProwiN (Borowski et al., 2010) und Profile-P (Riese et al. 2015). Das Schulwissen beschreibt dabei curriculare Inhalte und Fähigkeiten bis zum Niveau der Sekundarstufe II. Das universitäre Wissen geht darüber hinaus und schliesst das Wissen ein, das in fachwissenschaftlichen Lehrveranstaltungen gelehrt wird.

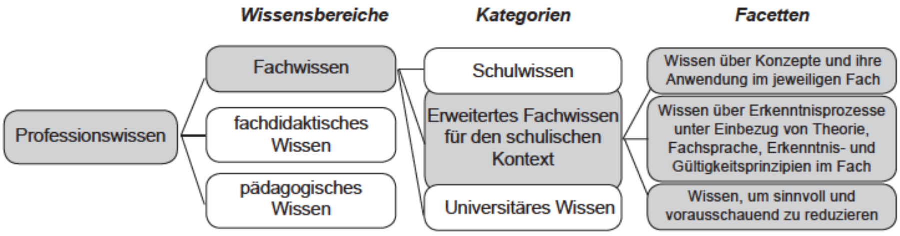


Abbildung 1: Einbettung des erweiterten Fachwissens für den schulischen Kontext in das Modell des Professionswissens, angelehnt an Baumert & Kunter (2006) und Riese et al. (2015).

Das erweiterte Fachwissen wird hierbei jedoch keineswegs als «Niveaustufe» (Riese, 2009) zwischen dem Schulwissen und dem universitären Wissen definiert. Die dadurch implizierte Hierarchie führt zu der Vorstellung, dass es sich um eine stufenartig stei-

[2] Im Folgenden werden die Begriffe «erweitertes Fachwissen für den schulischen Kontext» und «erweitertes Fachwissen» (im Sinne einer Kurzform) synonym verwendet.

gende Komplexität zwischen den Kategorien handeln würde. Auch die von Woitkowski et al. (2011) vorgeschlagene Bezeichnung der «Fach-Stufen» empfinden wir aus den gleichen Gründen als unbefriedigend. Die in diesem Beitrag vorgeschlagene Bezeichnung «Kategorien des Fachwissens» ermöglicht die Loslösung von einer impliziten Hierarchie. Das erweiterte Fachwissen beschreibt dabei Wissen und Fähigkeiten, die es ermöglichen, Inhalte aus dem universitären Wissen und dem Schulwissen miteinander in Verbindung zu bringen. In Abgrenzung zum fachdidaktischen Wissen wird beim fachübergreifenden Konstrukt des erweiterten Fachwissens für den schulischen Kontext angenommen, dass der Einbezug der Lernendenperspektive (z.B. Wissen über Vorstellungen von Schülerinnen und Schülern) nicht gegeben ist. Es ist möglich, erweitertes Fachwissen aufzuweisen, ohne einen direkten Bezug zum unterrichtlichen Handeln herzustellen. Nicht nur Lehrkräfte, sondern auch Fachwissenschaftlerinnen und Fachwissenschaftler können, zumindest implizit, über ein hoch ausgeprägtes erweitertes Fachwissen in einzelnen Facetten oder deren Beschreibungen verfügen. In der Gesamtheit der Facetten kann das erweiterte Fachwissen allerdings als berufsspezifisch für Lehrkräfte angenommen werden. Das erweiterte Fachwissen beinhaltet dieser Definition nach drei Facetten (vgl. Abbildung 2).

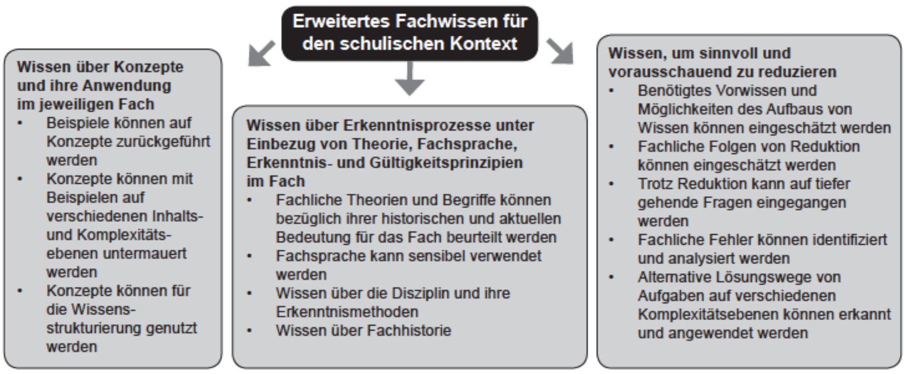


Abbildung 2: Die Facetten des erweiterten Fachwissens für den schulischen Kontext.

### 4.1 Wissen über Konzepte und ihre Anwendung im jeweiligen Fach

Dieser Facette liegt die Annahme zugrunde, dass die Inhaltsbereiche der jeweiligen Fächer über übergeordnete Konzepte verfügen. Konzepte zeichnen sich durch Übertragbarkeit auf verschiedene Phänomene und Sachverhalte der jeweiligen Domäne aus und sichern einen systematischen Zugang, der es erlaubt, neue Informationen in das Wissensnetz zu integrieren (u.a. Novak & Cañas, 2006). Diese lassen sich beispielsweise nicht nur in den Basiskonzepten und fundamentalen Ideen (Bruner, 1977), sondern auch in wissenschaftlichen Konzepten wiederfinden. Sie müssen stets sinnstiftend mit Erklärungen und Beispielen vernetzt werden. Dieses Wissen würde sich, der Konzeption Shulmans (1986) folgend, als «substantive knowledge» widerspiegeln und ist dementsprechend deklarativ. Einzelne fachliche Sachverhalte können mithilfe dieses

Wissens auf ihre Konzepte zurückgeführt werden und im Umkehrschluss können die übergeordneten Konzepte auch mit Beispielen auf verschiedenen Inhalts- und Komplexitätsebenen untermauert werden. In Abgrenzung zum konzeptuellen Wissen und zur Verwendung von Basiskonzepten, im Sinne eines strukturierenden Elements von fachlichen Lernsituationen, müssen Lehrkräfte wissen, warum ein bestimmter Inhalt oder ein Konzept den zentralen Inhalten bzw. Konzepten der Disziplin zugeordnet wird, während andere eher eine randständige Zuordnung erfahren. Die Konzepte müssen daher selbst erkannt, benannt, voneinander abgegrenzt und innerhalb einer Wissensstrukturierung miteinander in Verbindung gesetzt werden können.

Für Geschichtslehrkräfte spielt beispielsweise das Verständnis von folgenden Konzepten eine massgebliche Rolle: Die industrielle Revolution und die Französische Revolution können als Beispiele für verschiedenen Arten von Revolutionen auf die zugrunde liegenden «meta concepts» «Wandel», «Prozess», «Entwicklung», «Veränderung», «Ursache» und «Folgen» zurückgeführt werden. Zudem spiegelt sich in den verwendeten Termini das «substantive concept» zu «Revolution» wider (Günther-Arndt, 2014). Für Biologielehrkräfte wiederum ist es von grosser Bedeutung, das Basiskonzept der Kompartimentierung mit den Konzepten «Kompartiment» und «Organell» in Verbindung zu bringen. Obgleich die beiden Konzepte der Einfachheit halber teilweise synonym verwendet werden, müssen sie voneinander abgegrenzt werden können. Als «Kompartiment» bezeichnet man die Summe der Reaktionsräume einer Art, wohingegen «Organell» auch als Bezeichnung für eine funktionelle Struktur in der Zelle ohne eine umschliessende Membran (z.B. Ribosomen, Centriolen) gelten kann.

### 4.2 Wissen über Erkenntnisprozesse unter Einbezug von Theorie, Fachsprache, Erkenntnis- und Gültigkeitsprinzipien im Fach

Ein fundiertes Verständnis von fachlichen Begriffen und Theorien erachten wir als zentral. Dieses Wissen schliesst auch Wissen über die Genese von allgemeinen Theorien und Begriffen in epistemologischer Hinsicht ein. Hierdurch wird auch der Bezug zur «syntactic structure», d.h. zum Wissen über die Disziplin (Shulman, 1986), deutlich. Lehrkräfte sollen in ihrer jeweiligen Disziplin z.B. wissen, wie Wissenschaftlerinnen und Wissenschaftler Forschungsfragen aus Modellen und Theorien entwickeln bzw. welche Standards unter welchen Bedingungen als etablierte methodische Standards für die Erhebung von Daten gelten. Dazu sollten die Grundstrukturen bezüglich fachspezifischer Erkenntniswege verstanden worden sein. Hier wird auch der Bezug zu Windschitls (2004) «disciplinary knowledge» im Sinne von «knowledge of domain-specific methods of investigation» deutlich.

Die Nähe zu den Konstrukten «Nature of Science» und «Nature of History» sowie zu den epistemologischen Überzeugungen (z.B. Sicherheit des Wissens) ist, wie oben beschrieben, unverkennbar. Für «syntactic knowledge» gilt jedoch eine höhere Disziplinspezifität als für die beiden anderen Konstrukte und insbesondere als für die epistemologischen Überzeugungen. Hinsichtlich der Lehrkräftebildung wird davon ausgegangen, dass für den Erwerb des entsprechenden Wissens ähnliche Lerngelegenheiten notwendig sind wie für die Genese eines adäquaten Verständnisses von «Nature of Science» (Abd-El-Khalick & Lederman, 2000; Hodson, 2009). Die eigene Erfahrung im Bereich der Erkenntnisgewinnung in der Disziplin, die für Lehramtsstudierende ohnehin nur in geringem Masse vorgesehen ist, hat sich dabei als unzureichend erwiesen und ist um spezielle Methodenkurse sowie explizite und reflexive Komponenten zum Thema zu erweitern (Schwartz, Lederman & Crawford, 2004). Verfügen Lehrkräfte über das entsprechende Wissen, können sie im Unterricht eher eine Verbindung zwischen den Konstrukten zum Wissenschaftsverständnis und den Fachinhalten herstellen (Clough & Olson, 2012).

Ein fundiertes Verständnis von fachlichen Begriffen und Theorien ermöglicht der Lehrkraft auch eine sensible Verwendung von Fachsprache. Dieser Facette ist darüber hinaus ein Zugang zur Fachhistorie inhärent. Beispielsweise müssen Biologielehrkräfte wissen, inwiefern neue Theorien auf älteren aufbauen und inwiefern in den Biowissenschaften fachübergreifend gearbeitet wird. Die Entdeckung der DNA-Struktur als Doppelhelix mit Basenpaaren durch Watson und Crick folgte z.B. auf wichtige Vorarbeiten wie Paulings Erkenntnisse zu helikalen Proteinstrukturen und Franklins, Goslings und Wilkins' Röntgenbeugungsdiagrammen. Die angewendeten Methoden, die zur Erkenntnisgewinnung beitrugen, lassen sich nicht einer einzigen Disziplin zuordnen. Mathematiklehrkräfte müssen sich hinsichtlich der Fachsprache der Tatsache bewusst sein, dass sich Definitionen in der Mathematik durch ihre formallogische, symbolische Strenge von Definitionen in anderen Fächern und in der Umgangssprache unterscheiden. Auch für Physiklehrkräfte spielt der Aspekt eine Rolle; der Begriff «Kraft» hat in der Physik nicht immer die gleiche Bedeutung wie im Alltag.

### 4.3 Wissen, um sinnvoll und vorausschauend zu reduzieren

Diese Facette beinhaltet Einschätzungen über die fachlichen Rahmenbedingungen eines Sachverhalts. Wenn ein Sachverhalt auf konzeptueller Ebene verstanden wurde, ist es der Lehrperson möglich, das benötigte Vorwissen und die Möglichkeiten des Aufbaus von weiterführendem Wissen auf diesen Sachverhalt auf inhaltlicher Ebene einzuschätzen. Dies basiert auf rein fachlicher Ebene auf dem von Ball et al. (2008) beschriebenen «horizon knowledge» («awareness of how mathematical topics are related over the span of mathematics», Ball et al., 2008, S. 403) sowie dem von Loch (2015) beschriebenen curricularen Wissen. Des Weiteren werden in dieser Facette ein Wissen über die fachlichen Folgen von Reduktion und deren Reflexion verortet. Obwohl es hierbei um didaktische Reduktionen geht, grenzt auch Loch (2015) diese Facette vom fachdidaktischen Wissen ab, weil es sich hier um eine sachlogische (mathematische) Reflexion der fachlichen Inhalte handelt. Innerhalb dieser Facette werden Fragen aufgeworfen wie z.B. «Zu welchen fachlichen Ungenauigkeiten könnte eine Reduktion führen?». Ebenso wird es der Lehrkraft möglich, auf tiefer gehende Fragen der Schülerinnen und Schüler einzugehen. In der Terminologie der Michigan-Group (Ball et al., 2008) gehören diese Wissensaspekte zum «specialized content knowledge».

Fachliche Fehler bezüglich eines Sachverhalts können durch das erweiterte Fachwissen leichter auf ihre Ursache zurückgeführt werden. Dieses Erkennen von fachlichen Fehlern ist ohne einen Bezug zur Schülerin oder zum Schüler zu verstehen und daher abzugrenzen vom Antizipieren typischer Vorstellungen von Schülerinnen und Schülern (Ball et al., 2008) und vom Umgang damit im Unterricht, was zum fachdidaktischen Wissen gehört. Es kann jedoch als Grundlage betrachtet werden, um fachdidaktisches Wissen (z.B. über mögliche Vorstellungen von Schülerinnen und Schülern) zu generieren.

Alternative Lösungswege für Aufgaben, wie auch schon von Riese et al. (2015) beschrieben, kann es auf verschiedenen Komplexitätsebenen geben. Das erweiterte Fachwissen ermöglicht es der Lehrperson, sich innerhalb dieser Komplexitätsebenen flexibel zu bewegen. Für Physiklehrkräfte kann hier der Induktionsstrom als Beispiel gelten. Sie sollten wissen, dass sich die Richtung des Induktionsstroms mit der lenzschen Regel (Schulwissen), aber auch mithilfe der Maxwell-Gleichungen (universitäres Wissen) erklären lässt. Sie sollten zudem konzeptuell verstanden haben, wie die lenzsche Regel aus den Maxwell-Gleichungen hergeleitet werden kann. Hier wird auch deutlich, inwiefern das erweiterte Fachwissen eine Brücke zwischen beiden Fachwissenskategorien schlägt. Geschichtslehrkräfte wiederum sollten einschätzen können, welche fachlichen Folgen Reduktionen bewirken, z.B. die Kürzung oder die Übersetzung von Quellen. Die Kürzung einer Quelle etwa bedeutet eine subjektive Auswahl, aus der gegebenenfalls eine Änderung des Sinngehaltes resultiert; bei einer Übersetzung können Termini verwendet werden, die möglicherweise zu einer verzerrten Wiedergabe des zeitspezifischen, historischen Sinnkontextes führen.

## 5 Das erweiterte Fachwissen für den schulischen Kontext als Leitlinie für die Gestaltung universitärer Lehrveranstaltungen

Durch das explizite Aufzeigen von Verknüpfungen zwischen universitärem Wissen und Unterrichtsinhalten kann sich berufsrelevantes Fachwissen besser entwickeln (Hoover, Mosvold, Ball & Lai, 2016). Für das erweiterte Fachwissen als der von uns beschriebenen berufsspezifischen Komponente des Fachwissens sind deshalb an der Universität geeignete Lerngelegenheiten zu etablieren. Abschliessend zeigen wir daher auf, inwiefern das Konstrukt des erweiterten Fachwissens für den schulischen Kontext als konzeptuelle Grundlage für Lehrveranstaltungen für angehende Lehrkräfte in verschiedenen Fächern genutzt werden kann. Dabei sind die beschriebenen Facetten des Modells des erweiterten Fachwissens grundsätzlich für Lehramtsstudierende und Lehrkräfte aller Schulstufen gleichermassen relevant. Unterschiede ergeben sich lediglich in der inhaltlichen Konkretisierung des Wissens für die einzelnen Facetten, nicht aber in den grundsätzlichen Erwartungen hinsichtlich der Fähigkeiten. Diese Massnahmen werden innerhalb des Projekts PSI-Potsdam in verschiedenen Teilprojekten und unterschiedlichen Fächern realisiert.

Durch die explizite Vermittlung des erweiterten Fachwissens wird versucht, die Berufsrelevanz der universitären fachlichen Inhalte deutlicher darzustellen. Beispiele aus der Mathematik zeigen bereits, dass dies erfolgreich sein kann (Ableitinger, Kramer & Prediger, 2013). Eine Möglichkeit stellt die Durchführung fachwissenschaftlicher Lehrveranstaltungen ausschliesslich für Lehramtsstudierende dar, die explizit auf das erweiterte Fachwissen fokussieren. Ausserdem wird, wie auch von Heinze et al. (2016) vorgeschlagen, in fachdidaktischen Lehrveranstaltungen universitäres Wissen auf schulische Kontexte bezogen. Eine neu konzipierte Lehrveranstaltung in Seminarform wird additiv zu einer Fachvorlesung fakultativ angeboten. Die Lernaufgaben innerhalb dieser Lehrveranstaltungen werden auf der Grundlage der Facetten des erweiterten Fachwissens entwickelt und beziehen sich dabei auf die Anwendung des universitär erworbenen Wissens in berufsfeldbezogenen fachlichen Lerngelegenheiten. Das geschieht beispielsweise mittels der Erstellung von Concept-Maps zu zentralen schulrelevanten inhaltlichen Themen. Des Weiteren werden schulische Materialien auf inhaltlicher Ebene dekonstruiert und anschliessend rekonstruiert. Hierbei sind die Studierenden aufgefordert, Schulbuchtexte mithilfe von Leitfragen hinsichtlich ihrer fachlichen Qualität zu beurteilen und sich an Verbesserungsvorschlägen zu üben (z.B. evozierte Fehler bei der Darstellung von Ständen in einer Pyramide in Geschichtslehrwerken erkennen und alternative Darstellungsformen finden).

In einem weiteren Ansatz werden mit Übungsaufgaben, basierend auf dem erweiterten Fachwissen, universitäre Inhalte auf der Ebene des erweiterten Fachwissens reflektiert (Massolt & Borowski, 2017). Die Erwartung ist, dass dies nicht nur zu einer Verbesserung des Professionswissens der angehenden Lehrkräfte, sondern auch zu einer Steigerung der Motivation führt. Die Aufgaben schlagen die Brücke zwischen dem Schulwissen und dem universitären Wissen: Sie sollen aufzeigen, wie die beiden Kategorien des Fachwissens miteinander verbunden sind. Das erweiterte Fachwissen für den schulischen Kontext bietet demnach Anwendungsmöglichkeiten in der universitären Lehre, die dazu beitragen, fachliche Studieninhalte für Studierende spürbar berufsrelevanter zu gestalten, und kumulatives Lernen an der Universität ermöglichen.

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## 2.2 Increasing the Perceived Relevance of University Physics Problems by Focusing on School-Related Content Knowledge

The second paper, (Massolt and Borowski, 2018), is published in the journal 'heiEDUCATION Journal'. The development of the problems, the data collection and the analysis were done by the author of this dissertation under supervision of Prof. Dr. Andreas Borowski. The paper was written by the first author - also the responsible author - with the help from Andreas Borowski.

*Joost Massolt and Andreas Borowski*

# Increasing the Perceived Relevance of University Physics Problems by Focusing on School-Related Content Knowledge

**Abstract.** The goal of this study is to increase the perceived relevance of university content knowledge courses by physics pre-service teachers. To achieve this goal problem sets discussed in tutorial groups, which are part of first-year physics courses for university physics majors and physics pre-service teachers, were modified in such a way that some of the problems were geared towards the content knowledge category "school-related content knowledge" (SRCK). This category describes conceptual knowledge that is teacher-specific. Conceptual problems based on this category were developed and introduced in weekly tutorials in two different courses (N = 75; N = 43 respectively) together with conceptual problems with no explicit school relevance and with regular, quantitative problems. Every week we asked students of a first- and a second-semester physics course to rate these problems with respect to perceived relevance and difficulty in a questionnaire. One finding is that when the content is more distant to physics taught at school, both conceptual problem types are perceived as more relevant by physics pre-service teachers than the regular, quantitative problems.

**Keywords.** Relevance, content knowledge, physics problems, physics

## Steigerung der wahrgenommenen Relevanz des universitären Wissens durch eine Fokussierung auf das erweiterte Fachwissen für den schulischen Kontext

**Zusammenfassung.** Ziel dieser Studie ist die Steigerung der wahrgenommenen Relevanz des universitären Wissens von Lehramtsstudierenden des Faches Physik. Hierzu wurden neue Aufgaben für Übungsgruppen zu Veranstaltungen des ersten und zweiten Semesters für Studierende der Fächer Physik und Lehramt Physik entwickelt. Diese Aufgaben basieren auf dem sogenannten „erweiterten Fachwissen für den schulischen Kontext". Diese Kategorie des Fachwissens beschreibt ein konzeptuelles Wissen, das berufsspezifisch für Physiklehrer ist. Hierauf basierende

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Aufgaben wurden zusammen mit konzeptuellen Aufgaben ohne Schulbezug und klassischen, quantitativen Aufgaben in wöchentlichen Übungsgruppen in zwei unterschiedlichen Veranstaltungen (N = 75 bzw. N = 43) eingesetzt. Die Aufgaben wurden von den Studierenden mit Hilfe wöchentlicher Fragebögen in Bezug auf wahrgenommene Relevanz und Schwierigkeit bewertet. Die Ergebnisse zeigen, dass die konzeptuellen Aufgaben von Lehramtsstudierenden als relevanter als die klassischen, quantitativen Aufgaben wahrgenommen wurden, wenn die Inhalte weiter vom Schulstoff entfernt waren.

Schlüsselwörter. Relevanz, Fachwissen, Schulwissen, Physik

## Introduction

Dropout rates in German university physics and physics teacher-training courses have been consistently high (Heublein et al. 2017). Part of the problem is the learning motivation of physics pre-service teachers (Albrecht 2011; Heublein et al. 2017). Evaluations of the teacher-education courses at the University of Potsdam showed that students often have difficulties seeing the connection between content knowledge taught in university courses and content knowledge they will need in their future teaching career (AG Studienqualität 2011). In addition, students reported that the physics content they were taught at university did not meet the needs of teachers (Merzyn 2004). They wish for more school-relevant content knowledge (Riese 2009) and a more pronounced connection between the content knowledge courses and the pedagogical content knowledge courses (AG Studienqualität 2011). Surveys at other universities showed that this is not just a problem in Germany (e.g. Koponen et al. 2016). A lower perceived relevance has a negative influence on motivation (e. g. Frymier, Shulman 1995; Keller 1983; Kember, Ho, Hong 2008). Since separation from the professional field and lack of motivation are seen as reasons for study discontinuation (Albrecht 2011; Heublein et al. 2017) and at the same time a particularly high physics teacher shortage in Germany is expected (Klemm 2015), there is a need for action.

Improving the connection between content knowledge courses and the pedagogical content knowledge courses can, for instance, be done by implementing supplementary learning materials or introducing additional courses. However, we think that a modification of the content knowledge courses themselves is important for improving this connection.

## Theoretical Background

### Relevance and Motivation

Increasing the relevance of learning material seems to have a positive effect on students' learning motivation. Relevance can be defined as a student's perception of whether the course instruction or content satisfies their personal needs, personal goals, or career goals (Keller 1983). In Keller's ARCS-model of instructional design relevance is one of the conditions that has to be met in order to improve the motivational appeal of instructional materials (Keller 1984). One effect is that learners become and stay motivated (Keller 1979; 1983). According to Keller, making content relevant to learners will increase their state motivation; this is the student's motivation to "situationally demonstrated characteristics" (Keller 2010, p. 16), e. g. a particular task at a particular time. To test this Frymier and Shulman (1995) used psychometric scales to measure the content relevance in classrooms and the motivation of students. They found a positive correlation between state motivation and relevance.

The utility value of a task (Wigfield, Eccles 1992), which refers to how a task is relevant to an individual's future plans, has been related to the 'identified regulation' construct but also to the most self-determined 'integrated regulation' construct of the self-determination theory (Ryan, Deci 2000; Wigfield, Cambria 2010). Deci et al. (1991) reported that self-determined behaviour leads to lower levels of dropout, higher academic achievements and higher levels of conceptual understanding. Observation of self-determination also correlates positively with intrinsic learning motivation (Deci, Ryan 1985; 2002).

Furthermore, Kember et al. (2008) interviewed undergraduate students with regard to aspects that motivated or demotivated them in their study. They found that establishing relevance was seen by students as very important for their motivation to learn; of the eight principal facets that were identified after analysis of the transcripts, establishing relevance was cited most often. They also found that relevance and stimulating intrinsic motivation seemed to be related.

### Professional Knowledge of Physics Teachers

Shulman already described the professional knowledge of (prospective) teachers in 1986. He differentiated content knowledge (CK) from pedagogical content knowledge (PCK) and pedagogical knowledge (PK). The PCK of teachers has furthermore been recently described extensively (e. g. Gess-Newsome 2015). In the acquisition of PCK, CK plays a vital role (Baumert et al. 2010; Krauss et al. 2008; Terhart 2002). It is, however, still unclear how much and what type of content knowledge teachers need. Shulman (1986; 1987), following Schwab (1964; 1978), distinguished the substantive structure of knowledge from its syntactic structure. Anderson and Clark described the substantive structure of knowledge as “knowledge of general concepts, principles and conceptual schemes, together with the detail related to a science topic” (2012, p. 316; after Hashweh 2005) and the syntactic structure as “understandings and beliefs about the nature of scientific knowledge, its philosophy, history, generation, validation and dissemination” (2012, p. 316; after Hodson 2009). Ball (1990) summarizes these structures as ‘knowledge of the discipline’ and ‘knowledge about the discipline’.

In multiple studies of the professional knowledge of (prospective) physics teachers (e. g. Kirschner 2013; Riese 2009; Walzer, Fischer, Borowski 2014; Woitkowski, Riese, Reinhold 2011), CK has been further specified (see Woitkowski, Borowski (2017) for an overview). A knowledge category is established that describes the teacher-specific content knowledge. Riese (2009) distinguishes three different levels within the content knowledge of (prospective) physics teachers: school knowledge, deeper knowledge and university knowledge. School knowledge here is defined as the knowledge described in the school curriculum (years 7–10); university knowledge describes the knowledge that is learned in a university course that is not part of the school curriculum. The deeper knowledge is defined as ‘deeper and networked knowledge with regard to the school curriculum; school physics from a higher perspective’ (2009, p. 80). A confirmatory factor analysis indicates evidence for the existence of these different levels. Riese showed that the levels ‘school knowledge’ and ‘deeper knowledge’ seem to be more important for actions in the context of physics teaching than university knowledge. However, an increasing level of empirical item difficulty between the three levels was not found. There is therefore no evidence for a hierarchical relation between the three levels. Because of this Woitkowski et al. (2011) described the CK of (prospective) physics teachers with three steps instead of levels. Deeper knowledge is here defined as ‘knowledge that bridges between the school knowledge and the university knowledge’. It is an ‘explicit combination of school knowledge and university knowledge’. ‘Identifying misconceptions’ is one of the other characteristics of the deeper knowledge. In the project Profile-P (Riese et al. 2015), a similar differentiation of CK into school knowledge, university knowledge and here deeper school knowledge is used. The deeper school knowledge describes knowledge that is important in a school context, like identifying and using different approaches to a problem, identifying boundary conditions for using a physical model and the ability to simplify problems for different target groups. It clearly describes abilities that are teacher specific. The existing definitions of the knowledge category that described the teacher-specific content knowledge are, however, subject-specific and include only the substantive structure and not the syntactic structure of knowledge.

## School-Related Content Knowledge

### The SRCK-Model

Based on the studies in physics portrayed in the previous section and on studies describing the teacher-specific content knowledge of mathematics teachers (e. g. Ball, Thames, Phelps 2008; Heinze et al. 2016; Loch 2015), the category school-related content knowledge (SRCK) has been modeled for several subjects in a multi-disciplinary group within the project PSI-Potsdam (Professionalisation – School-Placement-Studies – Inclusion). It takes both the substantive and syntactic structures of content knowledge into account and describes knowledge and abilities specific for teachers (see figure 1, Woehlecke et al. 2017). SRCK is characterized by interconnected knowledge and describes a conceptual knowledge that enables an overview of the respective subject; it is university content knowledge reflected on school-related contexts. SRCK is necessary for a deeper understanding of content relevant in school-situations; it prepares for planning, teaching and analysing lessons.

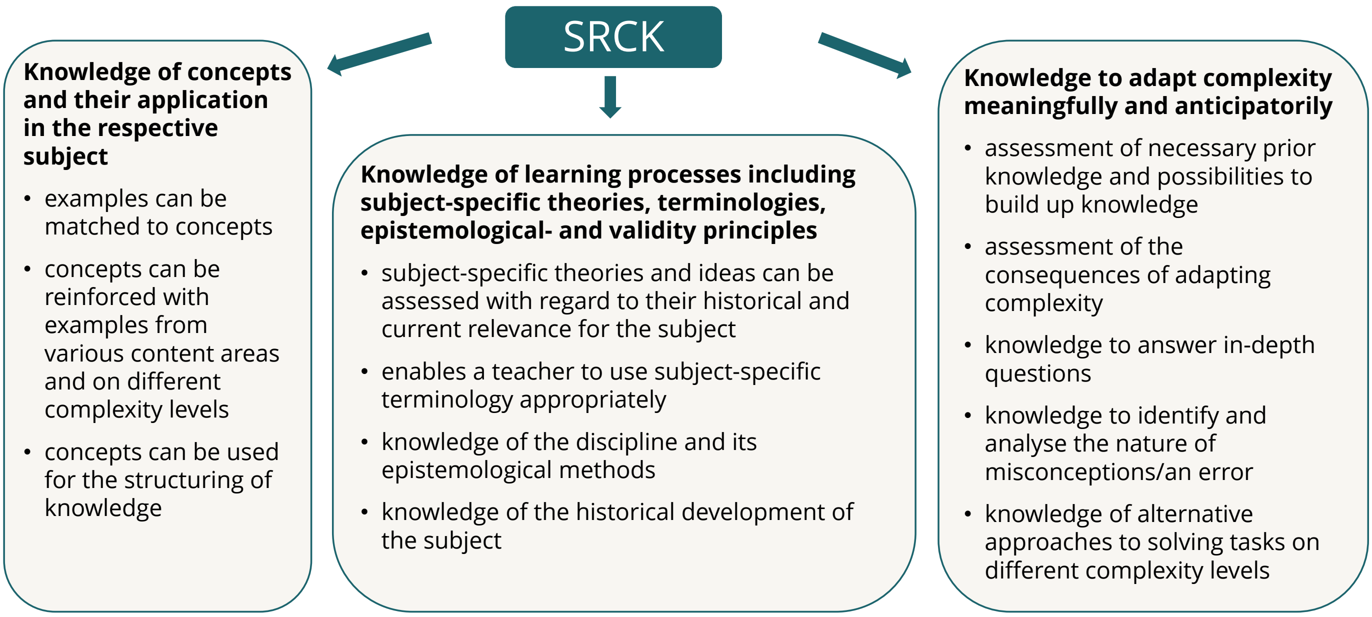


Figure 1: Facets of School-Related Content Knowledge (Woehlecke et al. 2017).

## SRCK in Physics

SRCK offers the possibility to improve the connection between CK- and PCK courses by modifying the former. The knowledge described in the facet 'Knowledge of learning processes including subject-specific theories, terminologies, epistemological- and validity principles' prepares physics pre-service teachers for a content analysis as one part of a lesson preparation. They are able to assess the importance of a specific theory to the field. Knowledge of the development of, for instance, quantum physics allows for a historical approach to teach this subject.

The facet 'Knowledge to adapt complexity meaningfully and anticipatorily' describes knowledge which prepares them for developing their own problems to be used in class. They are able to adapt the complexity of a phenomenon and they know what consequences a reduction of the complexity has. For instance, when comparing the total kinetic energy of two objects at the bottom of a frictionless plane (figure 2), teachers often reduce the complexity of the problem by stating that the cylinder is rolling without slipping and that the plane is a frictionless plane. However, teachers should know that a frictionless plane prevents the cylinder from rolling without slipping; there will be no force providing the torque around the centre of the cylinder.

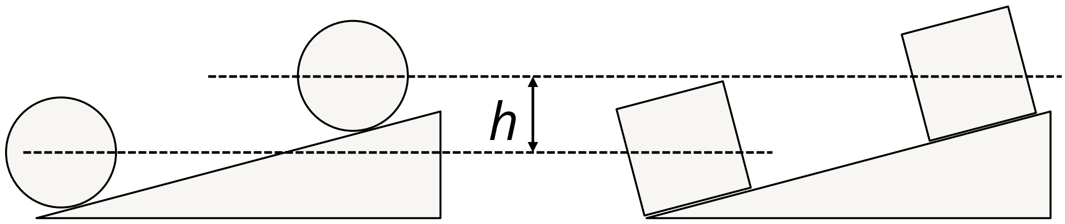


Figure 2: Two objects on a frictionless plane. Which object arrives at the bottom with more total kinetic energy? When the cylinder is rolling without slipping, the block cannot glide without friction on the same plane. Problem adapted from Mazur (1997).

The facet 'Knowledge of concepts and their application in the respective subject' enables teachers to come up both with relevant examples when explaining a concept or with counterexamples when rebutting a statement. Given the statement that a net force working on an object is always doing work teachers should be able to come up with a counterexample (in this case, the centripetal force on a body rotating with uniform speed).

### Interventions based on SRCK

The knowledge in SRCK can therefore add school relevance to a course that mainly focuses on university knowledge. Additionally, it serves as an anchoring point for a better connection between CK and PCK. Although there has been a lot of research on the degree of professional knowledge of physics (pre-service) teachers (see, for instance, Woitkowski, Borowski 2017), to our knowledge there have been no studies on the effect of an intervention using the teacher-specific knowledge to adapt courses. In the project PSI-Potsdam, several interventions in multiple subjects are planned to modify teacher training courses based on SRCK. This includes additional seminars accompanying lectures which are specific for pre-service teachers. The learning tasks in these seminars use the model of SRCK to apply university content knowledge in a school-based setting, e.g. the construction of concept maps for school-related themes and the deconstruction and subsequent reconstruction of educational materials (see Woehlecke et al. 2017). Tutorial problems based on SRCK have been used in courses for pre-service teachers in both chemistry and physics. In this paper, we will focus on the latter.

## Context of the study

The university physics courses in Germany consist of lectures, tutorial groups and laboratory experiments. Especially in the first few semesters, physics pre-service teachers and physics majors mostly attend the same courses (Deutsche Physikalische Gesellschaft 2010). Often, no distinction between these two groups is made in these courses; they attend the same lectures and write the same final exams. Both groups of students are usually combined in one course for reasons of capacity but also because of the long-held conviction that the scientific education of physics pre-service teachers should closely follow that of physics majors (e. g. Großmann 2002). In physics, the topics that are taught in one course are usually seen as a prerequisite for the consecutive courses. Therefore, when two groups attend the same series of courses, both groups should be brought to and tested at the same level. It would otherwise lead to differences in understanding between the groups in the consecutive courses. This means that both groups should also write the same final exams. Both groups of students also attend the same tutorial groups, where weekly problem sets are discussed. Both physics majors and physics pre-service teachers solve the problems on these problem sets in preparation of the weekly tutorial groups. The problems discussed in these tutorials constitute a very important preparation for the final exam. Typical problems used in problem sets are, however, quantitative problems. The problems do not have any explicit school relevance, which for the purpose of this paper means that they do not make a connection between the university physics and school physics.

## Research Questions

We would like to begin this paragraph with presenting our first research question:

*To what extent do problems that are based on SRCK increase the perceived relevance of the problem sets by physics pre-service teachers?*

SRCK bridges the gap between university and school knowledge. Since it describes knowledge and abilities that are teacher-specific, the expectation is that problems that are based on this knowledge and on these abilities will have a positive effect on the perceived relevance of the university content knowledge and therefore the motivation of the physics pre-service teachers (e. g. Keller 1983). Leufer and Prediger (2007) constructed exercises with the aim of connecting the university mathematical knowledge of pre-service mathematics teachers with their school knowledge. They showed that a similar approach can have a positive effect on perceived relevance and motivation. Bauer and Partheil (2009) also saw a positive effect of using exercises that connect these two knowledge categories. We therefore expect the problems based on SRCK to have a higher perceived relevance by physics pre-service teachers than the regular problems. We do not expect to see this effect with physics majors. To test this hypothesis, we have added a second research question:

*What are the differences in the perceived relevance of the problems based on SRCK by physics pre-service teachers and physics majors?*

The problem sets, aimed at both physics majors and physics pre-service teachers, are a very important preparation for the final exam. The difficulty and overall level of the courses should not be influenced by our intervention. The developed problems should therefore be on the same level of difficulty as the problems they replace. As a result, the difficulty of the problems based on SRCK should not differ significantly from that of the regular problems.

## Methodology

At the university of Potsdam, the weekly problem sets contain about five to seven problems. In two first-year experimental physics courses (see table 1), two of these regular problems are replaced. The problems are solved and then rated by students with respect to perceived relevance using a questionnaire. As a measure of the difficulty of the problems, the students also rated them with respect to perceived difficulty.

Table 1: Total number of students participating. Courses took place in the academic year 2016/2017.

| Course | Semester | Physics Majors | Physics Pre-service Teachers (PST) |
|---|---|---|---|
| Experimental Physics 1 | 1 | 28 | 47 |
| Experimental Physics 2 | 2 | 19 | 24 |

### Courses

Experimental Physics 1 is a first-semester course for physics majors and physics pre-service teachers. The topic of this course is mechanics (kinematics, dynamics and statics). Like most of the introductory physics text books (Buschhüter, Spoden, Borowski 2017) the course starts with the basics of physics. The content in this course is therefore close to the physics taught at school. In the final third of the semester (the final four weeks), subjects that are not discussed at school are introduced, such as compression, shear stress and Fourier transformations. The level of mathematical abstraction is increased by introducing differential equations in the discussion of damped (forced) oscillations. With regard to the content taught, this semester is therefore more distant than the physics courses taught at school.

The content of Experimental Physics 2 (electrostatics, electrodynamics, magnetism, optics) is also more distant to school physics. The level of mathematical abstraction is higher than in Experimental Physics 1 throughout this course, mainly because of the increased mathematical abstraction of, for instance, the Maxwell Equations and, for instance, the recurring use of the differential equations that were introduced in Experimental Physics 1.

## Problem types

### Description of problem types

The regular problems are defined as quantitative problems without any explicit school relevance (see table 2). Two of these problems are replaced with conceptual problems. One of these conceptual problems is a problem based on the SRCK-model. Because it is based on this model, it has explicit school relevance. The other problem also focuses on conceptual knowledge, but it is not based on the knowledge described in the SRCK model. It therefore has no explicit school relevance. This problem type is added as a control-problem in order to find out whether any differences in perceived relevance originated from the transition from quantitative to conceptual problems or from the addition of school relevance. Examples of the conceptual problem types can be found in figure 3 and figure 4.

Table 2: Description of the problem types used in the problem sets. The problem types marked with * are the newly designed problems.

| Course | Semester | Physics Majors |
|---|---|---|
| No school relevance | 'Regular Problems' | 'Conceptual-without' * |
| School relevance | | 'Conceptual-SRCK' * |

Hovercraft
Suppose you are sitting in a soundproof, windowless room aboard a hovercraft moving over flat terrain. Which of the following situations can you determine from inside the room?
The hovercraft...
1. ... is moving with a constant velocity.
2. ... is moving with a constant acceleration.
3. ... is on an inclined plane.
4. ... is rotating with a constant angular velocity.
5. ... is in rest.

Explain your reasoning.

Figure 3: Example of a conceptual problem without explicit school relevance (after Mazur 1997).

Is Newton's law of gravity wrong?

A smart student studied Newton's law of gravitation. She came to the following conclusion: "I can prove Newton's theory of gravity is wrong. The sun is 320,000 times as massive as the earth, but only 400 times as far from the moon as the earth is. Therefore, the force of the sun's gravity on the moon should be twice as big as the earth's and the moon should go around the sun instead of around the earth. Since it doesn't, Newton's theory of gravity must be wrong!"

Explain what is wrong with this reasoning.

Figure 4: Example of a conceptual problem based on SRCK (after Redish 2003). The problem is based on the facet "Knowledge to adapt complexity meaningfully and anticipatorily" and the sub-facet "knowledge to identify the nature of misconceptions/an error".

## Problem design

No influence is exerted on the design of the regular problems; often problems from a previous semester are recycled. The conceptual problems without school relevance are constructed using problems from, among others, Mazur (1997) and Redish (2003). Based on the facets of SRCK, several descriptions of problems based on SRCK are developed (see table 3). The descriptions are used for the development of problems based on SRCK.

Table 3: Problem descriptions based on the sub-facets of SRCK.

| Sub-facet | Problem description |
|---|---|
| Assessment of the consequences of adapting complexity | A definition or an explanation in a textbook is given. The content is often reduced in an educational sense. The student should answer one or more of the following questions:<br>• What are the physical consequences of the reduction?<br>• What information was left out?<br>• In which situations will this be problematic?<br>• In which situations will this not pose any problems?<br>• What is the connection between the reduced school knowledge and the university knowledge? (bottom-up approach)<br>• How can you reduce the university knowledge to arrive at the school knowledge? (top-down approach)<br>Given is a solution to a problem by a hypothetical student. The student should answer one or more of the following questions:<br>• What approximations were made by this student?<br>• Are these approximations correct?<br>• Are there situations in which this approximation cannot be made?<br>• [...] |

| Sub-facet | Problem description |
|---|---|
| Knowledge to identify and analyze the nature of misconceptions/a mistake | A statement or solution by a hypothetical student is given. The student should answer one or more of the following questions:<br>• Are the statements/solutions incorrect? Why?<br>• What physical mistakes were made by this student?<br>• How can one improve the statement/solution?<br>Given is incorrect information from a textbook. The student should answer one or more of the following questions:<br>• What are the mistakes?<br>• Explain your reasoning. |

## Questionnaire

Both the new problems and the regular problems are solved on equal terms at home and discussed in tutorial groups (see figure 5). At the start of every tutorial group (13 weeks in total), students are asked to fill in a questionnaire in which they have to rate the problems with regard to their relevance for the students' later occupation (on a scale of 1 to 6, students had to answer the question "To what extent do the problems prepare you for your future career?", where 1 equals "no preparation" and 6 equals "very good preparation") and difficulty ("How difficult were the problems?", where 1 equals "very easy" and 6 equals "very difficult"). The questionnaire contains six additional items that are of no interest to this paper.

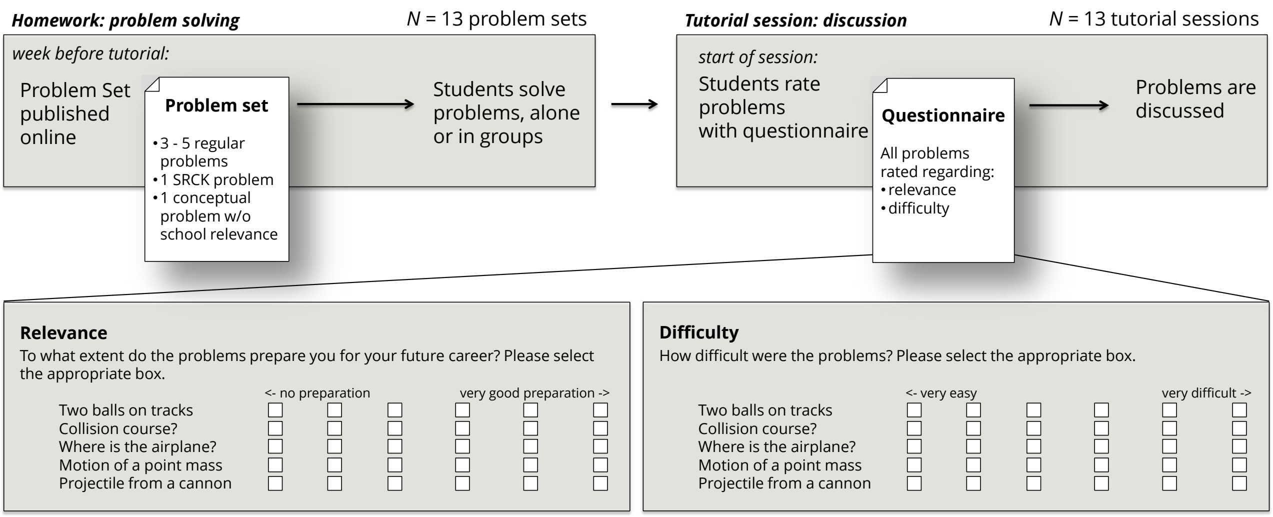


Figure 5: Visualization of the experimental setup. At the start of every tutorial group, the students were asked to rate all the problems on the problem set with regard to (among others) perceived relevance and difficulty.

The students were told that the questionnaire was used to evaluate the problems used in the course in general; they are not aware of the fact that problems are modified to increase the perceived relevance of the problem sets.

## Results

### Validity of Measurement Scale and Problems

#### Quality of the Relevance Scale

Because of time constraints a single-item measure for relevance is used. A validation study (after de Boer et al. 2004) is done to find the correlation between the single-item measure and the multiple-item 'value/usefulness' scale from the intrinsic motivation inventory (Deci, Ryan 2003). In this study, $N = 32$ third-semester physics students are asked to rate two problems they solved as part of their weekly problem set with the use of the single-item measure of relevance and with four items from the 'value/usefulness' subscale of the intrinsic motivation inventory. The reliability of the multiple-item scale was found to be high ($\alpha = .94$).

In order to get evidence for the validity of our single-item measure we have calculated the correlation between both scales. A strong correlation was found: $r_s = .75$, $p < .001$. A strong correlation persists when the item that is used in both the single-item measure and multiple-item scale is removed to get rid of the autocorrelation: $r_s = .72$, $p < .001$. Although it is not possible to calculate the reliability of a single-item scale, the strong correlation with the multiple-item scale provides evidence of our scale's reliability.

#### Content Validity of Problems

The instructors of both courses that are responsible for the problem set analysed the newly developed problems first. The problems that are used in this study are all accepted by these instructors and are therefore seen as important for the preparation of the final exam. The problems were thus accepted with regard to content validity.

All the problems that are used are assigned to their respective problem type (see table 2). For this, we use a problem-assignment manual which is based on problem-design instructions (see section *Problem design*). The first step is to determine whether the problem was a purely reproduction problem ("Give the equation to calculate the gravitation interaction between two planets") or not. Pure reproduction problems are not considered for further analysis. As a second step, the problems have to be labelled on the basis of their qualitative or quantitative nature. If the problem (or part of a problem) includes operators, as, for instance "calculate" or "determine" in which mathematical skills play an important role, the problem is considered a regular problem. This includes the drawing of diagrams using value pairs first to be calculated. When a problem is not considered a regular problem, the problem is seen as a conceptual problem. In a next step, the problems have to be assessed using the manual described in the earlier section. If we are able to assign the problem to one or more of the descriptions of a problem based on SRCK, the problem is considered a problem based on SRCK. If the problem does not fit these descriptions, the problem is treated as a conceptual problem without school relevance.

The inter-rater reliability of the assignment of problems to problem type was tested with two trained assistants and considered substantial (Cohen's kappa = 0.78 / 0.80), according to Landis and Koch (1977).

## Experimental Physics 1

In this section, the ratings by both student groups of all the problems from the first semester course Experimental Physics 1 are presented. For clarity, the results are presented per construct.

### Perceived Relevance

An analysis using a two-tailed independent t-test showed that the questions based on SRCK are perceived as more relevant ($M = 4.07$; $SD = 0.28$) by physics pre-service teachers than by physics majors ($M = 3.33$; $SD = 0.36$), $t(23) = 5.75$; $p < .001$, see figure 6. The effect size, calculated with Cohen's d, was considered huge (Sawilowsky 2009): $d = 2.25$. The conceptual problems without school relevance were also perceived as more relevant by the physics pre-service teachers ($M = 3.95$; $SD = 0.25$) than by the physics majors ($M = 3.58$; $SD = 0.35$), $t(36) = 3.95$, $p < .001$, however, with a much smaller effect size, albeit still very large: $d = 1.22$. The difference in perceived relevance of the regular problems between both groups was not significant: $M = 3.86$; $SD = 0.39$ (PST), $M = 3.81$; $SD = 0.41$, $t(78) = 0.61$; $p = .54$; $d = 0.14$.

Analysis of variance shows no statistically significant differences between the perceived relevance by physics pre-service teachers of the three problem types

F(2,71) = 1.91, p = .16. There is, however, a significant difference in the perceived relevance by the physics majors: $F(2,71) = 7.94$; $p < .001$; $\omega^2 = .16$. A Tukey's HSD post-hoc analysis shows that the problems based on SRCK are perceived by physics majors as significantly less relevant than the regular problems, $p < .001$; $d = 1.19$. The differences between the other problem types is not significant.

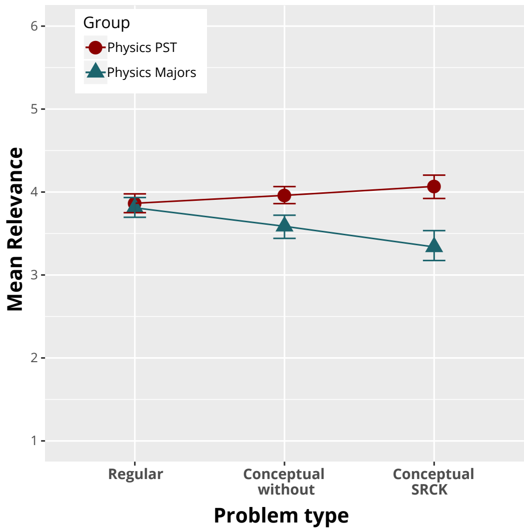


Figure 6: Perceived relevance of problems by problem type by physics pre-service teachers and physics majors for the course "Experimental Physics 1". The error bars show the 95 % confidence intervals.

The content that is taught in the last third of the semester is more distant to the physics taught at school. An analysis of variance of the problems used in the last third of the semester shows an effect of the problem type on the students' perceived relevance, $F(2,21) = 4.58$; $p < .05$; $\omega^2 = 0.23$, see figure 7. A Tukey's HSD post-hoc analysis shows that the perceived relevance of the SRCK problems is higher than the regular problems ($p < .05$) with a very large effect size, $d = 1.58$. There are no significant differences between the regular problems and the conceptual problems without school relevance ($p = .92$) and between the conceptual problems without school relevance and the problems based on SRCK ($p = .12$). For the physics majors, no significant differences are found in the perceived relevance between the problem types, $F(2,21) = 3.09$; $p = .067$.

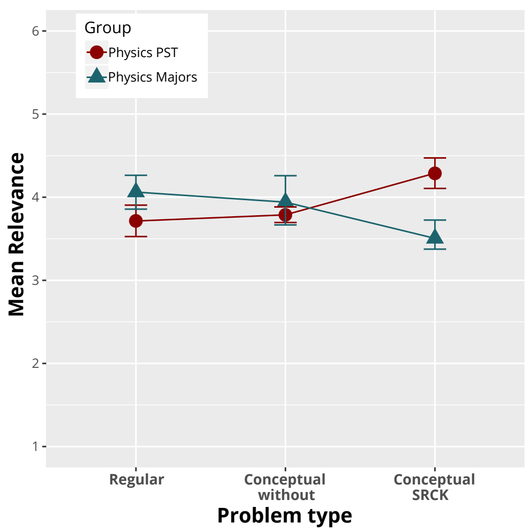


Figure 7: Perceived relevance of problems by problem type by physics pre-service teachers and physics majors for the final third of the semester for the course "Experimental Physics 1".

## Difficulty

Analysis of variance shows that the physics pre-service teachers report no significant differences in the difficulty of the problem types, $F(2,71) = 3.02$; $p = .055$, see figure 8. Significant differences are found with the physics majors, $F(2,71) = 6.75$; $p < .01$, $\omega^2 = 0.13$. The post-hoc analysis shows that both the problems based on SRCK ($p < .05$) and the conceptual problems without school relevance ($p < .01$) are considered easier than the regular problems, with a medium to large effect size ($d = 0.72$ and $d = 0.87$ respectively).

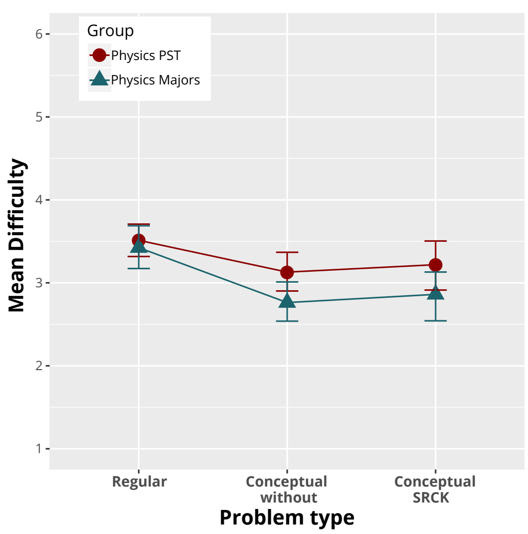


Figure 8: Reported difficulty of problems by problem type by physics pre-service teachers and physics majors for the course "Experimental Physics 1".

Significant differences in difficulty between the problem types are not found in the last third of the semester for both groups, $F(2,21) = 0.18$; $p = .84$ (Physics PST); $F(2,21) = 0.99$; $p = .39$ (Physics majors).

## Experimental Physics 2

In this section, results from the second semester course Experimental Physics 2 are discussed per construct.

### Perceived Relevance

In this semester, the two-tailed independent t-test again shows significant differences between the perceived relevance of the problems based on SRCK by the physics pre-service teachers ($M = 4.33$; $SD = 0.52$) and the physics majors ($M = 3.63$; $SD = 0.46$), $t(24) = 3.63$; $p < .01$; $d = 1.42$, see figure 9. The physics pre-service teachers also consider the conceptual problems without school relevance to be more relevant ($M = 4.13$; $SD = 0.36$) than the physics majors ($M = 3.60$; $SD = 0.36$), $t(25) = 2.82$; $p < .01$, again with a much smaller effect size: $d = 0.94$. Again, there is no significant difference between the perceived relevance of the regular problems by both groups: $M = 3.49$; $SD = 0.64$ (PST), $M = 3.66$; $SD = 0.30$ (Physics majors), $t(86) = -1.42$; $p = .16$; $d = 0.30$.

Using analysis of variance we find significant differences in the perceived relevance between the problem types by physics pre-service teachers, $F(2,74) = 12.34$; $p < .001$; $\omega^2 = 0.23$. A post-hoc test shows significant differences between the problems based on SRCK and the regular problems ($p < .001$; $d = 1.36$) and between the conceptual problems without school relevance and the regular problems ($p < .01$; $d = 0.98$). For the physics majors, there are no significant differences between the problem types, $F(2,74) = .098$; $p = .91$.

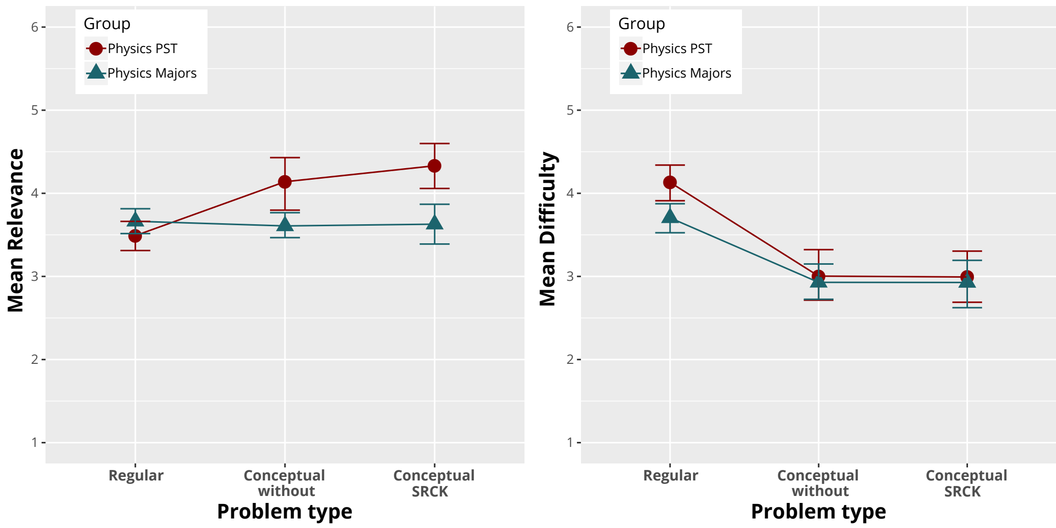


Figure 9: Perceived relevance of problems by problem type by physics pre-service teachers (top left) and physics majors (top right) and reported difficulty of problems by physics pre-service teachers (bottom left) and physics majors (bottom right) for the course "Experimental Physics 2".

### Difficulty

In both groups, significant differences are found between the problem types: $F(2,74) = 25.45$; $p < .001$; $\omega^2 = 0.39$ (Physics PST) and $F(2,74) = 16.8$; $p < .001$; $\omega^2 = 0.29$ (Physics majors), see figure 8. For the physics pre-service teachers both the conceptual problems without school relevance ($p < .001$; $d = 1.61$) and the problems based on SRCK ($p < .001$; $d = 1.65$) are considered to be easier than the regular problems. The physics majors also consider these problem types to be easier than the regular problems: $p < .001$; $d = 1.34$ respectively $p < .001$; $d = 1.28$.

## Discussion

### Perceived Relevance

The goal of this study is to investigate the effect of conceptual problems based on SRCK on the perceived relevance of physics problem sets. The results indicate that the physics pre-service teachers perceive the problems based on SRCK to be more relevant than physics majors do. The conceptual problems without school relevance are also considered to be more relevant by the physics pre-service teachers, though with a much smaller effect size. However, both groups are asked to rate the problems with regard to their relevance for the students' future career. For physics majors, this question might be somewhat more difficult to answer since they might not have a clear idea of what their future career will look like.

The first semester course Experimental Physics 1 starts with the basics of physics. It is therefore very close to the content the students have learnt at school. It is not surprising then that the physics pre-service teachers do not see any difference in the perceived relevance of the problems based on SRCK compared to the other problems: the other problems already have school relevance, simply because the content they are based on is school content. In the final third of the semester, the content is more distant to school knowledge. Some of the topics are not discussed in school and the level of mathematical abstraction is higher. The physics pre-service teachers consider the regular, quantitative problems based on this content to be less relevant than the problems that were based on SRCK. Making the connection between the university physics and the school physics can therefore increase the perceived relevance of problems. We can see the same effect in the second semester: the content of Experimental Physics 2 is also more distant to school physics. The problems that are based on SRCK are therefore regarded as more relevant than the regular problems. Our work therefore indicates that using problems that are based on SRCK can have a positive influence on the perceived relevance of problem sets. These problems therefore have the potential for increasing the motivation of physics pre-service teachers. However, with the exception of the final third of Experimental Physics 1, the conceptual problems without explicit school relevance seems to have a similar effect on perceived relevance.

In the first semester course, the physics majors see the conceptual problems as less relevant to their future careers, although only the difference between the regular problems and the problems based on SRCK are statistically significant. In the second semester, there are no significant differences in the perceived relevance anymore. One explanation for this development might be that the students' idea of what to expect of physics in university is formed by their experience in secondary school. In secondary school exams, quantitative problems predominate (e. g. Schoppmeier, Borowski, Fischer 2012). They therefore expect a final exam that mainly focuses on this problem type. Having seen that the final exam of the first semester also contained conceptual problems, they conclude in the second semester that these problems also have relevance to their future career: they prepare them for the final exam. This suggests that the material used by instructors, like exams, can have an influence on what students consider relevant to their future career. Further research can focus on the question of what actually changes this perception and what the effect of this changing perception is on students' decision to stay in or drop out of their study.

## Difficulty

Both the physics pre-service teachers as well as the physics majors rate the difficulty of the two conceptual problem types in both semesters to be easier than the regular problems. For the physics pre-service teachers this effect is nevertheless not always statistically significant. It is, however, not clear to what extent the students are able to rate the difficulty of the problems. All problems are rated by the students before they are confronted with the solutions to the problems they have worked on. Just because the students regard a problem as easy does not automatically imply that the problem is correctly solved; a study by Leppavirta (2012) on the conceptual understanding of electromagnetics, for instance, shows that students can very confidently give incorrect answers. This means that students might think a problem is easy, even though they are not able to solve it. Further research on the relation between the estimated and real difficulty of different types of physics problems is therefore necessary.

Even though the students mainly considered the conceptual problems to be easier than the regular problems, the instructors – by including the problems into the weekly problem sets – accept the conceptual problems as an important exam preparation for all the students.

## Limitations

The results show that physics pre-service teachers consider the physics problems based on SRCK to be more relevant than regular problems. However, the generalizability of this result is still questionable. In both semesters, only 13 problems based on SRCK were rated by a maximum of 75 and 43 students, respectively. The group of students from the second semester was a subset of the first semester and the study was only performed at one university. To overcome the problem of using the same group of students, the study was repeated in the winter semester of 2017/2018; the results of this study will be published in a later article.

The students rate the problems before they are discussed in the tutorial group to control for differences in discussion between the tutorial instructors. However, one could raise the question whether the perceived relevance of a problem might be different after a problem is discussed, that is, after the students are shown the solution and the reasoning behind the problem. This could of course have an influence on the perceived relevance, but also on the perceived difficulty of the problem.

In the assignment of the problems to their respective types, we have forced ourselves to make a decision about the problem type. If a problem involves a sub-problem where a calculation has to be made, the whole problem is considered a regular one. However, another sub-problem within the same problem could have been a conceptual problem. The time-constraints regarding the use of the questionnaire have forced us to allow the students to rate the problems as a whole and not the individual sub-problems.

Experts have not yet validated the model of SRCK on which the problems are based. The question is therefore: do the problems based on SRCK really prepare pre-service physics teachers for planning, teaching and analyzing physics lessons? Do experts agree on our theory that these problems represent knowledge that is specific for physics teachers? To answer these questions, a validation study with expert teachers is planned.

## Conclusions

As we have seen, it is possible to increase the perceived relevance of physics problems by basing the problems on the knowledge and abilities specific to physics teachers described in the model of school-related content knowledge. However, it is also possible to achieve this goal with conceptual problems that have no explicit school relevance. For these problems to have a higher perceived relevance than regular, quantitative problems, the university content that both conceptual problem types are based on should, however, not be too close to the physics content taught in secondary school.

Furthermore, conceptual problems are on average seen as less difficult than quantitative problems. The question remains whether students are able to rate the difficulty of conceptual problems equally well as that of quantitative problems.

In conclusion, by modifying CK courses we have shown a possible way to improve the relevance of these courses for physics pre-service teachers. We think that such a modification does not automatically imply a decrease of the level of the course. Because the connection between university knowledge and school knowledge is already made in CK courses, this connection could serve as a preparation for a better connection between CK courses and PCK courses. Usually, this connection is only made in the PCK courses. A focus on conceptual knowledge, with or without explicit school relevance, offers a possible way to connect school knowledge and university knowledge in CK courses.

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## 2.3 Perceived Relevance of University Physics Problems by Pre-Service Physics Teachers: Personal Constructs

The third paper (Massolt and Borowski, 2020) is published in the journal 'International Journal of Science Education'. It is written by the first author, who is also the responsible author, with the help from Prof. Dr. Andreas Borowski. The conceptualisation of this study, the data collection and the analysis were done by the author of this dissertation under supervision of Andreas Borowski.


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# Perceived relevance of university physics problems by pre-service physics teachers: personal constructs

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**ABSTRACT**

Pre-service physics teachers often do not recognise the relevance for their future career in their university content knowledge courses. A lower perceived relevance can, however, have a negative effect on their motivation and on their academic success. Several intervention studies have been undertaken with the goal to increase this perceived relevance. A previous study shows that conceptual physics problems used in university physics courses are perceived by pre-service physics teachers as more relevant for their future career than regular, quantitative problems. It is however not clear, what the students' meaning of the construct 'relevance' is: what makes a problem more relevant to them than another problem? To answer this question, $N = 7$ pre-service teachers were interviewed using the repertory grid technique, based on the personal construct theory. Nine physics problems were discussed with regards to their perceived relevance and with regards to problem properties that distinguish these problems from each other. We are able to identify six problem properties that have a positive influence on the perceived relevance. Physics problems that are based on these properties should therefore potentially have a higher perceived relevance, which can have a positive effect on the motivation of the pre-service teachers who solve these problems.

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Motivation; physics education; pre-service teachers; repertory grid

## Introduction

### *Perceived relevance and lack of motivation*

In German universities, physics major students and pre-service secondary school physics teachers generally attend the Experimental Physics courses – which make up a large part of the first semesters of their bachelor programme – together. These courses are however mostly aimed at the physics major students. Many pre-service physics teachers do not perceive these courses as relevant for their future career (AG Studienqualität, 2011; Merzyn, 2004). This problem extends beyond Germany and beyond the subject of physics: Koponen, Asikainen, Viholainen, and Hirvonen (2016) report the same issues in mathematics courses at Finnish universities.

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Relevance can be defined as a 'personally meaningful connection to the individual' (Priniski, Hecht, & Harackiewicz, 2018, p. 12). Priniski et al. (2018) conceptualise relevance along a continuum of personal meaningfulness, starting at a personal association level and reaching to identification. Their relevance framework is based on the four-phase model of interest development – where relevance serves as a trigger for situational interest (Hidi & Renninger, 2006) – the expectancy-value model of achievement-related choices (Eccles et al., 1983) and the self-determination theory by Deci and Ryan (1985) – where relevance is seen as part of the internalisation process. Many studies show that a lower perceived relevance can have a negative effect on academic achievement and on the retention of knowledge (Harris, Heneghan, & McKay, 2003; Malau-Aduli et al., 2013; Petty & Cacioppo, 1981, 1986). It has also been connected to a lower learning motivation (Frymier & Shulman, 1995; Kember, Ho, & Hong, 2008; Sass, 1989; Weaver & Cottrell, 1988). A result of a low perceived relevance of university courses by students can be, next to the possible results described above, the discontinuation of their study (Albrecht, 2011; Heublein et al., 2017).

### *Improving perceived relevance*

It is therefore important for the content in a course to be perceived as relevant by the students, since perceived relevance is likely to have a positive effect on educational outcomes like an increase in subjective task value, interest development and autonomous motivation (Priniski et al., 2018). What is not directly clear is how to improve the perceived relevance of course content. Frymier and Houser (1998) studied the interaction between immediacy and relevance in a $2 \times 2$ experimental design (high/low immediacy and high/low relevance) since they found that immediacy and relevance both were linked to a higher motivation, but were also associated with one another (Frymier & Shulman, 1995). They find that only immediacy has an impact on motivation and learning; relevance does not. This could be explained by not having sufficiently changed the relevance in the experimental design, but also by the fact that the relevance was determined by coders and not by the students. They suggest further research into factors that enhance relevance.

Personalising the learning experience, as described by Walkington and Bernacki (2014), is one of these possible factors. They theorise that a personalised learning experience can lead to students discovering more personally meaningful types of relevance. Another possible factor that enhances relevance is making a link between the course content and applications in the later profession of students. Owen (2017) linked the course content in a research methods course to the personal or professional goals of students. The content was perceived as more relevant when it was explicitly linked to an application in their possible later profession. Similar studies have been conducted for the specific group of pre-service teachers. In these studies, the course content was related to the content knowledge category that described the teacher-specific knowledge (Dreher, Lindmeier, Heinze, & Niemand, 2018; Riese et al., 2015; Woehlecke et al., 2017). Stäcker, Ropohl, Steffensky, and Friedrichs (2018) developed learning opportunities for pre-service chemistry teachers where, among others, a content analysis of an everyday phenomenon is reduced for teaching purposes using knowledge maps. They find positive effects on the perceived relevance for some of the themes of the course. Massolt and Borowski (2018) used physics problems that were based on the model of school-related content knowledge (SRCK, Woehlecke et al., 2017) to increase the perceived relevance of problem sets for experimental physics tutorial groups by pre-service physics teachers. The SRCK model describes the content knowledge that is specific for teachers. The problems that are based on the facets described in this model are supposed to have a higher perceived relevance by pre-service physics teachers because they make a connection to their future career. They find that conceptual problems based on this model do have a higher perceived relevance by pre-service physics teachers than regular, quantitative problems. However, conceptual problems that are not based on school-related content knowledge are also found to have a higher perceived relevance than the regular problems. This suggests that there are more influences on the perceived relevance of these problems than just the problem properties derived from the facets of SRCK.

### *Relevance from the perspective of the receiver*

The question that remains is how students determine how relevant for their future career the content is to them. An answer to this question would provide us with indications on what exactly influences the perceived relevance, which can tell us how to adapt learning material in order to increase the perceived relevance of this material by students.

Many strategies that enhance the perceived relevance are theoretically determined (Keller, 1983; Sass, 1989; Weaver & Cottrell, 1988). In his ARCS model for motivational design (Attention, Relevance, Confidence, Satisfaction), Keller (2010) for instance mentions relating to goals, matching interests and tying to experiences as strategies to enhance relevance – strategies that all increase the personal meaningfulness (Priniski et al., 2018). Even though relevance can be seen as a 'personally meaningful connection' (Priniski et al., 2018, p. 12), these strategies are mostly developed from the perspective of the instructor (Muddiman & Frymier, 2009). According to Frymier and Houser, relevance:

> is a receiver based construct that varies from receiver to receiver, and it only exists in the mind of the receiver (1998, p. 127)

It is therefore also important to research these receiver-based constructs. To focus more on the student perspective, Muddiman and Frymier (2009) asked students what teaching behaviour and strategies teachers use to increase the perceived relevance. Most of the categories that were identified are in line with the strategies described in the model by Keller (1983). What is still unclear is whether the teacher behaviours that are listed by students make the content more relevant, or that the perceived relevance of the content is a result of being more motivated and engaged, also while some of the categories suggest that perceived relevance is seen as an outcome rather than a component of effective teaching (Muddiman & Frymier, 2009). Kember et al. (2008) asked students what typical approaches to teaching in their programme were, and what their effect upon their motivation was. Textbooks were for instance seen as more relevant when they showed that theory also applied to local issues and not just to issues that did not play a role locally. Relevance to everyday applications and current topics were also mentioned. Although the textbook example relates to teaching material, the other examples can also relate to teaching behaviours, which still leaves us with the question of whether perceived relevance is an outcome, or rather a component, of effective teaching.

### *Personal construct theory*

It is important to distinguish between explicit and implicit knowledge when asking students for their perspective on what influences relevance. In their study, Muddiman and Frymier (2009) directly asked the students to describe behaviour that has a positive influence on relevance. Kember et al. (2008) also used direct questions in his research on teaching approaches that influenced the motivation of students. The categories that were determined therefore only represent the students' explicit constructs.

Implicit constructs are determined by the tacit knowledge of students, which can be understood as a 'gut feeling' or intuition (Haldin-Herrgard, 2004). An appropriate tool to make tacit knowledge explicit is the use of the personal construct theory developed by Kelly (1955), which states that the way how future events are anticipated is guided by psychological processes. With this theory, he tried to explain why different people have different attitudes and views towards events in their world. One of his claims is that people use personal criteria – or constructs – to structure a meaningful world. Based on this theory, Kelly (1955) developed the role construct repertory test, now known as the repertory grid technique. This interview technique makes it possible to elicit personal constructs and thereby capture the subjective views of students in a structured way; it offers the possibility to describe their implicit knowledge (Fromm, 1995; Hillier, 1998; Jankowicz, 2004).

## Research questions

Massolt and Borowski (2018) find that students perceive conceptual physics problems as more relevant for their future career than calculational problems. The problems that they use in this study have however many additional properties in addition to them being conceptual or calculational. In this study, we want to find out which of these properties have a positive influence on the perceived relevance by pre-service physics teachers. The results will help us to create problems that are perceived as more relevant by students, but it will also give us more insight into the personal constructs that students use to determine how relevant a problem is to them. Our research question is therefore:

> Which problem properties have a positive influence on the perceived relevance of physics problems by pre-service physics teachers?

## Design and methods

### *Research design and sample*

In order to answer the research question, we have conducted interviews with $N = 7$ (6 male, 1 female) pre-service physics teachers at the University of Potsdam in the winter semester of the 2017/2018 academic year. Two participants were second-semester students, five participants were in the fourth semester of their study. All the participants received a small financial compensation.

In these interviews, nine problems that came from problem sets used in the first-semester course Experimental Physics 1 from that same year were discussed. Three of these problems were quantitative problems without explicit school relevance, three were conceptual problems that are based on the SRCK model and three problems were conceptual problems without explicit school relevance. The problems can be found in Appendix 1; for a detailed description of the problem types, see Massolt and Borowski (2018). The problems were randomly selected within their problem type from the full set of problems used in the course. The second-semester students were familiar with these problems since they attended Experimental Physics 1 in that year. Since some of the problems were unknown to the fourth-semester students, they were asked to prepare the interview by solving the problems. The interviews were recorded and later transcribed.

### *Interview technique*

Every problem was printed on a card and was randomly assigned a number (1–9). Each interview was structured according to the following scheme (see also Figure 1), derived from Fromm (1995) and Jankowicz (2004):

(1) The students were given the full set of nine questions and were asked to rate the problems with regards to their perceived relevance with the question 'to what extent do the problems prepare you for your future career?' (Massolt & Borowski, 2018). A scale from 1 to 6 is hereby used, where 1 refers to 'relevant' and 6 refers to 'not relevant'.
(2) In the second step, the students were given a set of three problems (for instance, problem numbers 1, 4 and 7). The students were asked 'Which two of these problems are the same in some important way, and different from the third?' They then had to explain what the two problems had in common, as opposed to the third. A possible answer could be, that two of the problems were 'easy' and the other 'difficult'. The

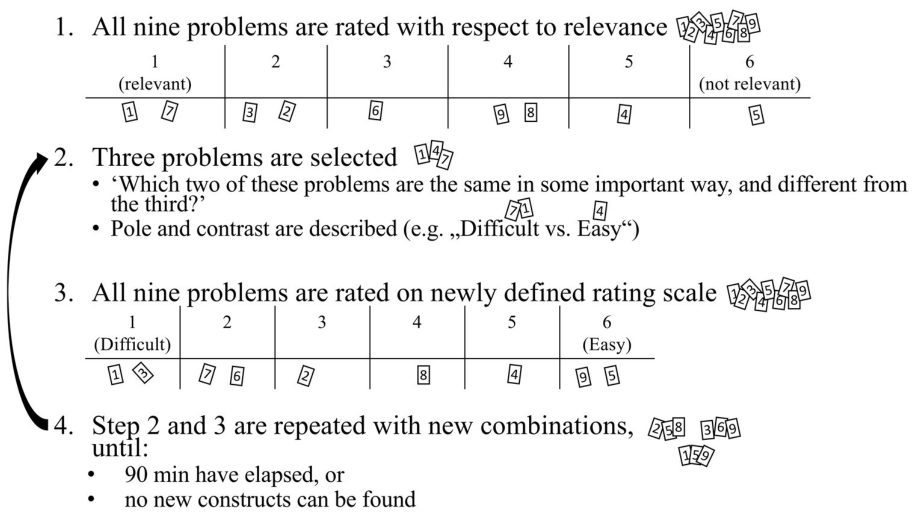


**Figure 1.** Flow chart of the interviews using the repertory grid technique. The numbered cards represent the problems used in the interview.

goal is to obtain a bipolar expression: here 'easy' is one of the poles of the expression and 'difficult' the contrast of this pole. This bipolar expression is the person's construct he or she used to describe the difference between the problems. If the student could not find a way to describe the differences between the problems or could not find any differences, a new set of three problems was presented.

(3) The newly defined construct was then presented as a rating scale, where 1 represents one pole of the construct ('easy'), and 6 the contrast to this pole ('difficult'). The students were then asked to rate all the nine problems on this new rating scale.

(4) Steps 2 and 3 were then repeated with a new set of three problems, until no new constructs could be elicited or until the interview lasted more than 90 min.

The same set of nine problems was used in every interview. The numbering of the problems was also identical for all the interviews and the same pattern for presenting the set of three problems was used.

### Analysis

Although the repertory grid technique is a way to find the personal constructs of participants, it is possible to get shared group constructs by combining the repertory grids that were obtained in single interviews (Honey, 1979; Jankowicz, 2004; Rojon, McDowall, & Saunders, 2018). In order to do this, the constructs have to be grouped together into inductively generated construct-categories. Next to that, a similarity score (Honey, 1979) has to be calculated for every construct in order to find out how much every construct is connected to relevance.

#### Similarity score

The similarity score reflects the extent to which the ratings on a construct matches the ratings on an overall construct (Honey, 1979; Jankowicz, 2004). In our study, this means that we are interested in the extent to which the ratings on the elicited constructs scales match the ratings on the relevance scale. For this reason, the following procedure was used to find the similarity score for each construct:

(1) Calculate the sum of differences for each construct. This is defined as the sum of the absolute differences between the relevance rating for a problem and the rating on the construct's scale for that problem over all the problems, see Equation (1). A lower sum of differences means that the construct is more similar to our overall construct, relevance.

$$\text{sum of differences} = \sum_{i=1}^{N} |(\text{Relevance rating})_i - (\text{Construct rating}_i)| \quad (1)$$

(2) It is up to the participant to define the description of the pole and the contrast to the pole in a construct. This means that one student could come up with a construct where 1 means 'easy' and 6 means 'difficult', whereas another student could reverse both meanings, so 1 means 'difficult' and 6 means 'easy'. Both constructs have the same meaning, but a calculation of the sum of differences would lead to different

values. A way to correct for this is to also calculate the sum of differences for a situation where one of the constructs is reversed (in our example: 1 – easy and 6 – difficult versus 1 – difficult and 6 – easy). Out of practical reasons, this calculation is done instead with the relevance rating reversed, which gives the same result.

(3) The *similarity score* is then defined as the absolute difference between the sums of differences calculated in step 1 and 2 (Rojon et al., 2018). A higher similarity score refers to the construct having a higher similarity to relevance.

For each participant, the constructs are then labelled with three indices H, I and L according to their similarity score. Constructs with similarity scores in the highest tercile *for that participant* are labelled 'H', in the lowest tercile with 'L' and in the intermediate tercile with 'I'.

When the sum of differences for the reversed construct (step 2) is smaller than that for the regular construct (step 1), then the construct's poles need to be reversed. So, if the reversed '1-difficult and 6-easy' leads to a lower sum of differences than '1 – easy and 6 – difficult', the poles that are used in the further analysis of this construct become '1 – difficult and 6 – easy', because in the remainder of this work we focus on the positive effect of a construct on perceived relevance.

### *Combining grids – construct categories*

All the constructs, independent on their similarity score and their tercile, are subsequently sorted into inductively generated construct-categories. Non-categorisable constructs go into 'miscellaneous'. These construct-categories describe the constructs within them and are also bipolar: they describe a pole and a contrast to this pole. The generation of these construct-categories has been done by two experts, independent of each other. Agreement on categories is then reached in discussion.

With the agreed construct-categories, the constructs are assigned to the construct-categories by two raters. Depending on the agreement between both raters, another adaption of the construct-categories can be carried out after which the agreement is calculated again.

Finally, the constructs that form the construct-categories are examined. Construct-categories that mainly have high- and intermediate level constructs (the H and I terciles) are retained whereas construct-categories with mainly low- and intermediate level constructs are discarded. The construct-categories that are retained then describe the personal constructs with a high to intermediate similarity to relevance; they give us information about the problem properties that are correlated with the perceived relevance of physics problems.

## Results

### *Implicit constructs*

An example of the results of a repertory grid interview can be found in Figure 2. The seven students generated a total of 56 constructs in the interviews ($M$ = 8.0; SD = 1.4). The constructs with their sum of differences score, the reversed sum of differences score, the similarity score and their tercile are listed in the table in Appendix 2.

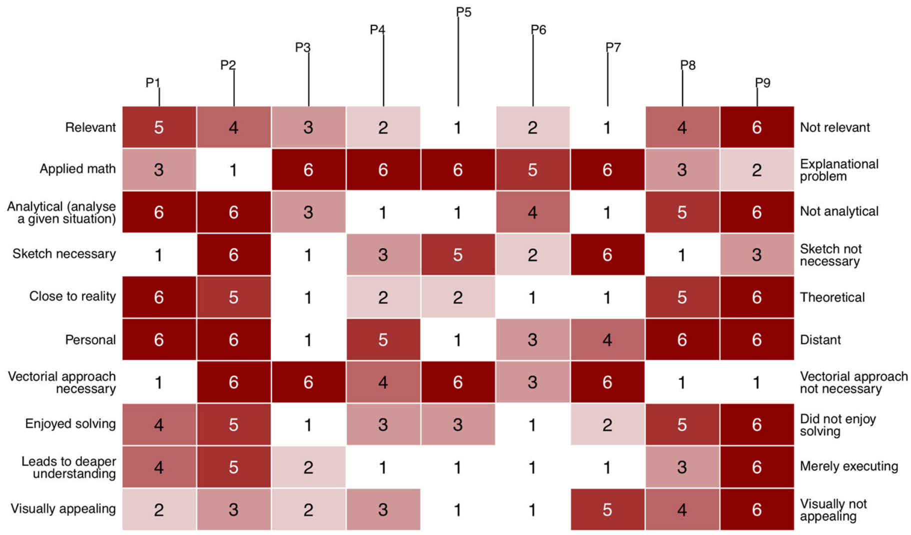


**Figure 2.** Repertory grid of participant #4. On the left the poles of every construct (1 on the scale), on the right the contrasts to these poles (6 on the scale). The indexes on the top indicate the problem number. The figure was made using the OpenRepGrid R package (Heckmann, 2016).

### *Construct categories*

The constructs were, not depending on their similarity score, independently sorted into inductively created construct-categories by two experts. A percentage agreement of 59% was reached between the two construct-categories systems. After discussion, a full agreement was reached. A total of 15 construct-categories were identified, including a 'miscellaneous' category. One construct-category with only one construct was created because of a theoretical interest into this construct-category; the other construct-categories had at least two constructs.

Another rater repeated the assignment of constructs to construct-categories. After an iterative and discursive process, a percentage agreement for the 56 constructs of 84% between both raters was reached. The Cohen's Kappa coefficient was calculated as $\kappa = 0.83$, which is considered 'almost perfect' (Landis & Koch, 1977).

The construct-categories shown in Table 1 have constructs with predominantly high- and medium-tercile constructs in them. These constructs have a high similarity to relevance and are retained for further analysis. A table with all construct-categories, their constructs and their respective terciles can be found in Appendix 3.

## Discussion

For categorising the 56 constructs, a total of 16 construct-categories were needed. This shows that these constructs clearly vary between students, they are really considered personal constructs. Not only the personal constructs vary between students, but also their relation to perceived relevance. One student, for instance, sees a calculational problem as less relevant (participant 1, construct 1), but for another student, a calculational

**Table 1.** Construct-categories with predominantly high- and intermediate tercile constructs with their constructs and their respective terciles.

| Construct-category | Constructs (number) | Tercile |
|---|---|---|
| Conceptual vs calculational | Thinking problem/calculational problem (1) | H |
| | Comprehension problem/calculational problem (50) | H |
| | Explanational problem/applied mathematics (22) | H |
| | Thinking/plug in (31) | H |
| | Explain/calculate (33) | I |
| | Calculational problem/thinking problem (40) | I |
| | Calculational problem/conceptual question (10) | L |
| Close to everyday life (on continuum scientific/ technological/personal) | Possible to experience problem personally/phenomenon rather in technical area (52) | H |
| | Close to reality/theoretical (25) | H |
| | Reference to real life/no reference to real life (46) | H |
| | Everyday/not everyday (12) | I |
| | Close to everyday life/distant to everyday life (3) | L |
| Mathematical requirements | Rather scalar/rather vectoral (15) | H |
| | Lower mathematical effort/higher mathematical effort (17) | H |
| | Vectoral approach not necessary/vectoral approach necessary (27) | I |
| Enjoyment (perceived personal enjoyment) | Fun/no fun (7) | H |
| | Fun solving/no fun solving (45) | H |
| | Enjoyed solving/did not enjoy solving (28) | I |
| Curricular order – school-relevant content | School relevant/not school relevant (related to content) (6) | H |
| | More a school problem/more a university problem (47) | H |
| Perceived learning gain | Leads to deeper understanding/merely executing (29) | H |
| | Increase in knowledge/no increase in knowledge (39) | H |
| Analytical | Analytical/not analytical (a given situation has to be analysed) (23) | H |

Notes: The constructs used in this table have, when necessary, first been reversed. The number behind the constructs refers to the construct number in Appendix 2.

problem has a higher perceived relevance (participant 2, construct 10). Both results can be seen as evidence for the theory that relevance is a receiver-based construct (Frymier & Houser, 1998). The definition of relevance by Priniski et al. (2018), where relevance is a 'personally meaningful connection to the individual', also fits these results: relevance is a personal connection, it differs from person to person.

### *Construct-categories that influence relevance*

Although relevance can be seen as a personal connection and varies from person to person, we managed to find categories that summarise these personal connections. The seven construct-categories in Table 1 summarise the personal constructs that are contained in each construct-category. An important step in analysing these construct-categories is determining their influence on the perceived relevance, especially in what direction they correlate. This is done by looking at the description of both poles in each personal construct.

*Conceptual vs. calculational:* Five out of seven constructs show that a problem that is rather conceptual leads to a higher perceived relevance. There are two remaining constructs (40 and 10) that work in the other direction: a calculational problem here has a higher relevance than a conceptual problem. Since these two constructs however only belong to an intermediate and low tercile, their influence on the construct-category as a whole can be neglected: these students do not see a strong relation with perceived relevance. Generally speaking, a problem that is more conceptual than calculational therefore has a higher perceived relevance. This is in line with the results from Massolt and Borowski (2018): they found that conceptual problems are considered more relevant than calculational problems.

*Close to everyday life (on continuum scientific/technological/personal):* All the constructs in this construct-category work in the same direction, which here means that a problem that is closer to everyday life is considered more relevant. This can also be found in the ARCS model for motivational design (Keller, 2010). 'Connection to previous experience' is seen here as a strategy for establishing relevance. 'Relevance to everyday applications and current topics' was also mentioned in the interviews by Kember et al. (2008) as having a positive influence on relevance.

*Mathematical requirements:* A vectoral approach to a problem can be considered a higher mathematical requirement than a mere scalar approach: both direction and quantity have to be considered. We can therefore conclude that all constructs point in the same direction: a problem with a lower mathematical requirement is considered more relevant. From the perspective of pre-service physics teachers, this can be understood in such a way that they feel that the higher mathematical requirements do not help to prepare them for their future career: as a future secondary school teacher, they do not use physics problems with very high mathematical requirements.

*Enjoyment (perceived personal enjoyment):* When the students enjoy solving the problem, they perceive the problem as more relevant. However, there are two reasons for not further considering this construct-category: it is unclear, whether more enjoyment leads to a more relevant problem or the other way around: a more relevant problem might lead to more enjoyment. The other reason for discarding this construct-category is that we are interested in possible problem properties that have an influence on the perceived relevance in order to modify physics problems. Perceived personal enjoyment cannot be seen as a property of a problem that can be tweaked easily, it is rather the result of other problem properties.

*Curricular order – school-relevant content:* When the content of a problem is more school relevant, the problem is perceived to be more relevant. Both constructs clearly work in this direction. It is a result that can of course be expected: school-relevant content has high relevance for the future career of pre-service physics teachers. Previous research has also shown that pre-service physics teachers wish for more school-relevant content in their studies to make it more relevant to them (AG Studienqualität, 2011; Riese, 2009).

*Perceived learning gain:* If students learn more when solving a physics problem, they consider the problem more relevant for their future career. Such a problem is, with regards to perceived relevance, preferred over a problem where a mere executing ('plug and chug') is sufficient for solving a problem. It is important to point out, that this is a perceived learning gain: the students have the idea that they learn more from a particular problem. There is however only a moderate relation between self-assessment of knowledge and cognitive learning, as pointed out by Sitzmann, Ely, Brown, and Bauer (2010). Self-assessments of knowledge are strongly related to affective evaluation outcomes (Sitzmann et al., 2010), which leads to the question whether the perceived learning gain is an outcome of the perceived relevance or the other way around.

*Analytical*: Even though it contains only one construct, this construct-category was created because of a theoretical interest in the construct; an analysis of a given situation (for instance with regards to the nature of misconceptions or approximations made by students) is a typical problem based on the facets of SRCK (Woehlecke et al., 2017) used in the study by Massolt and Borowski (2018). Such a problem, an analytical problem, is not typically used in physics problem sets. Research suggests that worked example problems can be beneficial for novice problem solvers (e.g. Sweller & Cooper, 1985; van Gog, Kester, & Paas, 2011). A variation on these problems, where students have to analyse an incorrect worked example, might have the same benefits. It is therefore also interesting to notice that these problems are maybe not just beneficial to, but that they are also seen as more relevant by pre-service physics students.

Out of the seven construct-categories that are described above, only the last one can be connected to the problems based on the facets of SRCK (Massolt & Borowski, 2018), the other ones are not described there. This is also what was expected since Massolt and Borowski (2018) found no statistically significant differences between the perceived relevance of the conceptual problems based on SRCK and the conceptual problems that are not based on the facets of SRCK. This suggests that there are more problem properties that influence perceived relevance than just the ones described in SRCK. At the same time, some of the problem descriptions based on the facets of SRCK do not show up in the personal constructs mentioned in this study. This can be explained by the fact that only three randomly selected problems based on SRCK were used in this study: not all the problem descriptions were covered in this set of problems.

What is interesting to note is that difficulty is not seen as a construct-category that correlates with perceived relevance: as can be seen in Appendix 3, 'Difficulty' shows up in one high, one low and three intermediate terciles and is therefore not seen as having an effect on perceived relevance. Massolt and Borowski (2018) show that conceptual problems have a higher perceived relevance by pre-service physics teachers than calculational problems. At the same time, these problems are also often considered easier. One would, therefore, expect the difficulty to have an influence on perceived relevance. The simple relation 'easier means more relevant' is therefore not valid.

### Limitations

Repertory grid interviews are very time-intensive. Because of this, the number of problems that can be discussed is limited. As said before, this can explain the fact that not all the descriptions of the problems used by Massolt and Borowski (2018) show up in the results. Using more problems in the interviews would therefore probably lead to more construct-categories. A different set of randomly selected problems could also lead to different construct-categories. Potentially the list of construct-categories and therefore the list of problem properties that have an influence on the perceived relevance of physics problems can be expanded.

Some of the construct-categories that were created only contain a few constructs. Because relevance is personal, but also because the constructs that were used to distinguish the problems from each other are *personal* constructs, there is a large variance in the personal constructs that were elicited. A different sample of students could, therefore, have an influence on the results. A larger sample size could improve the results and would probably lead to construct-categories with more constructs. The proportion of female to male in our sample (1–6) is somewhat low compared to the proportion in the population of pre-service physics students in both semesters (1–3.1 for the 2017/2018 cohort; 1–1.4 for the 2016/2017 cohort). It is however unclear what the influence of this unrepresentative proportion of female to male in the student sample is. In earlier research on perceived relevance by university students (e.g. Frymier & Shulman, 1995; Kember et al., 2008; Muddiman & Frymier, 2009) the results are not distinguished between female and male.

## Implications

Physics problems are not always seen as relevant by pre-service physics teachers. Since perceived relevance has an influence on motivation, it is important to increase the perceived relevance of these problems. It is possible to do this by using problems that

- are conceptual problems,
- are close to everyday life,
- have lower mathematical requirements,
- are based on school-relevant content,
- require more than merely ‘executing’, where students have the feeling they learn something,
- contain a situation that has to be analysed, like a student’s misconception.

We explicitly do not say that physics problems for pre-service physics students should for instance only have a low level of mathematical requirements or be only conceptual. It is part of a physics study to use advanced mathematics to solve quantitative problems. In Germany, it would also lead to other issues, since pre-service physics teachers often attend the same courses as physics major students, that require a higher level of mathematics. However, courses with a healthy mixture of, for instance, conceptual problems and calculational problems, of problems that are theoretical and those that are close to everyday life and of problems that require a high mathematical level and problems that require a lower mathematical level will already have a positive effect on the perceived relevance of these courses by pre-service physics teachers.

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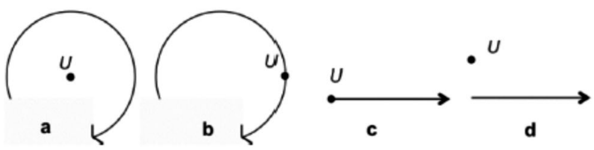
## Appendices

### *Appendix 1*

*Angular momentum* In the picture below you see the trajectories of four objects. All objects have a constant speed.

a) Give the direction of the angular momentum $\vec{L}$ with respect to the origin $U$ for the situation in which the object is at the tip of the arrow. Also state when the angular momentum is equal to zero.

b) For every situation, indicate whether the angular momentum is time-dependent.



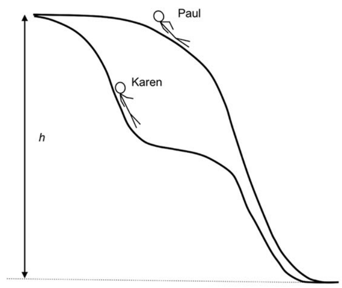

*Hint: A vector that is pointing out of the plane of the paper is usually indicated with "⊙"; a vector that is pointing into the plane of the paper is indicated with "⊗".*

**Figure A1.** Problem 1 (after Mazur, 2014).

*Cooling a drink* An ice cube with a mass $m_I = 40$ g and temperature $\theta_I = -1$ °C is put into a glass with $V_w = 200$ ml water at room temperature $\theta_W = 22$ °C. What temperature does the water reach, when the ice cube has melted? Ignore the heat transfer with the glass and the surroundings.

**Figure A2.** Problem 2 (after King & Regev, 1997).

*Water slide* Two water slides in a swimming pool have different shapes but both start at the same height *h*. Both slides have the same length. Two swimmers, Paul and Karen, start sliding down the slides at the same time, with no initial velocity. Ignore friction.



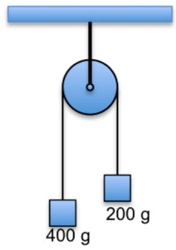

a) Explain who will have the highest speed at the end.

b) Explain who will be the first to reach the end of the slide.

c) Explain what your answer at a has to do with the term "conservative force".

*Hint: When necessary, look up what the term "conservative force" means*

**Figure A3.** Problem 3 (after Giancoli, 2008).




*The Atwood Machine* In the picture you see a so-called “Atwood machine” with two unequal masses tied to a rope ($m_{rope}$ = 2,0 g). The pulley has a mass $m_{pulley}$ = 20 g and a radius $r_{pulley}$ = 2,0 cm. The calculation of the acceleration of the masses can be simplified, when one makes certain approximations.

a) Name three possible approximations.

b) Explain what the effect of the approximations on the calculated value of the acceleration will be in comparison to the real value.

A possible calculation of the acceleration is shown in handwriting. An important step in this calculation is setting the tension in both parts of the rope as equal to each other. One can however only make this step, when a certain approximation has been made.

c) Explain what approximation this is. Also explain why the tension in both ropes can be set as equal because of this approximation.

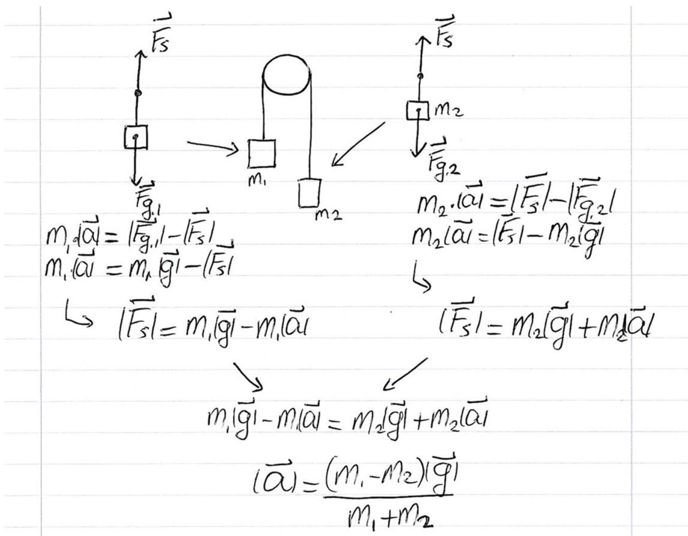
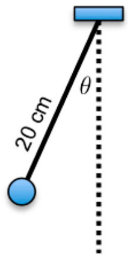
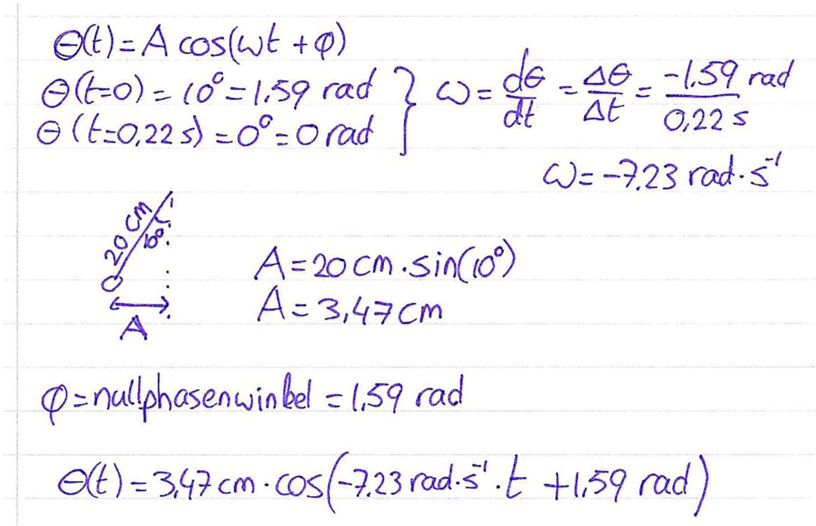



**Figure A4.** Problem 4.

*Pendulum* A (mathematical) pendulum with mass $m = 50$ g has a length $l = 20$ cm. It is pulled to an angle of $\theta = 10°$ (see picture) and released. After $t = 0{,}22$ s the pendulum first goes through equilibrium. With this information, Sarah is trying to find the equation of motion. Her calculation is shown below.



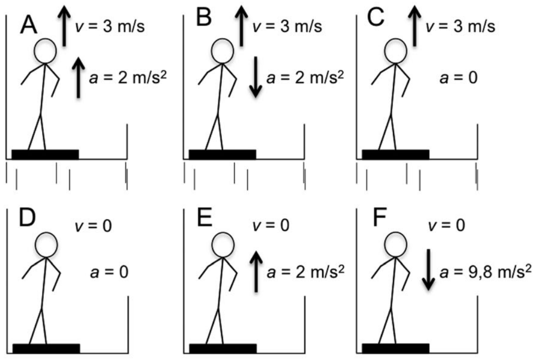




a) Unfortunately, Sarah's calculation is wrong. Explain what mistakes she made.

b) The angular frequency $\omega$ can be calculated in multiple ways. Describe two different methods to calculate the angular frequency.

**Figure A5.** Problem 5 ('nullphasenwinkel' is translated as 'zero phase angle').

*Elevator* Given are six situations where a person is standing on a scale in identical elevators. The scale indicates 60 kg when the elevator is at rest. In all situations, the elevator is moving with a specific velocity and acceleration (see the arrows). Rank these situations according to the indication on the scale, from high to low (take $g = 9{,}8\ \mathrm{m/s^2}$).




*Hint: It is possible that some scales indicate the same weight.*

**Figure A6.** Problem 6 (after O'Kuma, Maloney, & Hieggelke, 2004).

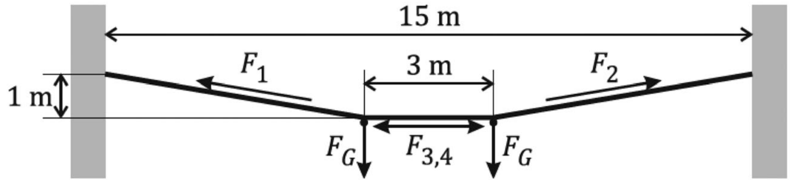
*Climbing scaffold* In a school text book a definition for potential energy is given: "raised objects, like the children on the climbing scaffold (see picture), or elastically deformed objects, have energy of position. In physics, this is called potential energy. The potential energy that an object has because of his position can be calculated from the work that is necessary to raise the object to this position. The potential energy has the same value as the work that was exerted on it to raise it." (from: Physik Gesamtband Sekundarstufe 1, Duden Paetec Schulbuchverlag, Berlin – Frankfurt a.M.).

a) Explain why this definition is not exactly correct.

b) Explain why this does not lead to problems in this situation (children on a climbing scaffold).

**Figure A7.** Problem 7.

*Overhead cable* Both of the overhead cables for a streetcar pull down on their supporting structure with $F_G = 150$ N. The supporting structure is spanning across the street of width $w = 15$ m. The cables have a distance of $d = 3$ m between them. Because of the load of the cables, the supporting structure is pulled down by $h = 1$ m (see the picture).




a) How big are the forces $F_1$ to $F_4$ in the supporting structure?

b) Why is the length of the supporting structure always bigger than the distance between the points where they are attached?

**Figure A8.** Problem 8 (after Lindner, 2003).

*Elastic collision in two dimensions* Ball 1 with mass *m* is colliding elastically, but not central, with an identical ball 2 at rest. The momentum $\vec{p}_1'$ of ball 1 after the collision makes an angle $\alpha$ with the momentum $\vec{p}_1$ before the collision.

a) Make a sketch of the situation. Draw the momentum vectors before and after the collision.

b) After the collision, ball 1 has a momentum component $\vec{p}_{1\perp}'$ perpendicular to its original direction of movement. How big is this component $\vec{p}_{2\perp}'$ for the second ball?

c) Show with a calculation that $\vec{p}_1'$ and $\vec{p}_2'$ are perpendicular to each other.

d) *Supplement* Determine the distribution of the kinetic energy across both balls after collision in dependence of the "scattering angle" $\alpha$.

*Hint: It can be useful to show the relation between the initial and final velocities with the help of the values of the perpendicular and parallel velocity and momentum components before and after collision: the energy "only" uses the square of the velocity and momentum*

**Figure A9.** Problem 9.

## *Appendix 2*

**Table A1.** Constructs with poles (poles/contrast) for every participant.

| Participant | Construct number | Pole/contrast | Sum of differences | Sum of differences – reversed | Similarity score | Tercile |
|---|---|---|---|---|---|---|
| 1 | 1 | Thinking problem/Calculational problem | 9 | 24 | 15 | H |
| 1 | 2 | Easy/Difficult | 12 | 23 | 11 | H |
| 1 | 3 | Close to everyday life/distant to everyday life | 13 | 20 | 7 | L |
| 1 | 4 | Basics/Application | 14 | 21 | 7 | L |
| 1 | 5 | Long problem text/short problem text | 12 | 19 | 7 | L |
| 1 | 6 | School relevant/not school relevant (related to content) | 7 | 20 | 13 | H |
| 1 | 7 | Fun/no fun | 9 | 26 | 17 | H |
| 1 | 8 | A lot of time needed/not a lot of time needed* | 20 | 13 | 7 | L |
| 2 | 9 | Open problem/closed problem* | 25 | 16 | 9 | I |
| 2 | 10 | Calculational problem/conceptual question | 19 | 20 | 1 | L |
| 2 | 11 | High diversity in requirements/low diversity in requirements* | 26 | 17 | 9 | I |
| 2 | 12 | Everyday/not everyday | 15 | 24 | 9 | I |
| 2 | 13 | Short problem definition/long problem definition | 13 | 32 | 19 | H |
| 2 | 14 | Complex/not complex | 19 | 22 | 3 | L |
| 3 | 15 | Rather vectoral/rather scalar* | 25 | 10 | 15 | H |
| 3 | 16 | Intuitive knowledge/expert knowledge (Problem is solvable with …) | 19 | 20 | 1 | L |
| 3 | 17 | Higher mathematical effort/lower mathematical effort* | 25 | 16 | 9 | H |
| 3 | 18 | Approximation necessary/ approximation not necessary | 18 | 21 | 3 | I |
| 3 | 19 | Long problem/short problem | 13 | 14 | 1 | L |
| 3 | 20 | Motivating design/non-motivating design | 14 | 21 | 7 | I |
| 3 | 21 | Possible to guess subject/not possible to guess subject (… by looking at appearance of problem) | 12 | 21 | 9 | H |
| 4 | 22 | Applied mathematics/ explanational problem* | 30 | 7 | 23 | H |
| 4 | 23 | Analytical/not analytical (a given situation has to be analysed) | 7 | 30 | 23 | H |
| 4 | 24 | Sketch necessary/sketch not necessary* | 24 | 17 | 7 | L |
| 4 | 25 | Close to reality/theoretical | 7 | 32 | 25 | H |
| 4 | 26 | Personal/distant | 14 | 27 | 13 | L |
| 4 | 27 | Vectoral approach necessary/ vectoral approach not necessary* | 30 | 11 | 19 | I |
| 4 | 28 | Enjoyed solving/did not enjoy solving | 10 | 27 | 17 | I |
| 4 | 29 | Leads to deeper understanding/ merely executing | 6 | 29 | 23 | H |
| 4 | 30 | Visually appealing/visually not appealing | 11 | 20 | 9 | L |
| 5 | 31 | Thinking/plug in | 12 | 23 | 11 | H |
| 5 | 32 | Difficult/Easy* | 21 | 16 | 5 | I |
| 5 | 33 | Explain/calculate | 15 | 22 | 7 | I |

(*Continued*)

**Table A1.** Continued.

| Participant | Construct number | Pole/contrast | Sum of differences | Sum of differences – reversed | Similarity score | Tercile |
|---|---|---|---|---|---|---|
| 5 | 34 | Solved rapidly/big effort | 16 | 17 | 1 | L |
| 5 | 35 | Open problem/closed, unambiguous | 17 | 18 | 1 | L |
| 5 | 36 | Descriptive/not descriptive (concerning images) | 11 | 22 | 11 | H |
| 5 | 37 | Only one subject/connection of multiple subjects | 18 | 23 | 5 | L |
| 5 | 38 | Complex problem definition/ problem definition understandable* | 24 | 15 | 9 | I |
| 5 | 39 | Increase in knowledge/no increase in knowledge | 7 | 26 | 19 | H |
| 6 | 40 | Calculational problem/Thinking problem | 13 | 16 | 3 | I |
| 6 | 41 | Closed problem/open problem* | 17 | 16 | 1 | L |
| 6 | 42 | Problem with numerical values/ generally valid problem* | 19 | 18 | 1 | L |
| 6 | 43 | Eager to discuss/not eager to discuss | 14 | 21 | 7 | I |
| 6 | 44 | High time investment/low time investment* | 20 | 17 | 3 | L |
| 6 | 45 | Fun solving/no fun solving | 8 | 23 | 15 | H |
| 6 | 46 | Reference to real life/no reference to real life | 9 | 22 | 13 | H |
| 6 | 47 | More a school problem/more a university problem | 12 | 21 | 9 | H |
| 6 | 48 | Not satisfied with performance/ satisfied with performance* | 20 | 11 | 9 | H |
| 6 | 49 | Imagination necessary/no imagination necessary* | 21 | 12 | 9 | H |
| 7 | 50 | Calculational problem/ comprehension problem* | 26 | 9 | 17 | H |
| 7 | 51 | More from own perspective/more from third person's perspective | 7 | 24 | 17 | H |
| 7 | 52 | possible to experience problem personally/phenomenon rather in technical area | 6 | 21 | 15 | H |
| 7 | 53 | Problem definition easy to understand/problem definition difficult to understand* | 21 | 14 | 7 | L |
| 7 | 54 | Easier to solve/more difficult to solve | 9 | 24 | 15 | I |
| 7 | 55 | Descriptively stated/less descriptively stated* | 22 | 17 | 5 | L |
| 7 | 56 | High degree of hints/lower degree of hints* | 24 | 11 | 13 | I |

Notes: The sum of differences refers to the sum of the differences between the construct score for every problem and the score on the relevance scale. For the 'sum of differences – reversed' the same calculation was used, but with the relevance scale reversed. The similarity score is calculated from both sums of differences. An asterisk* indicates that the poles need to be reversed. The constructs are divided into top (H), medium (I) and lower (L) terciles for every participant.

## Appendix 3

**Table A2.** Construct-categories with their constructs and their respective terciles.

| Construct-category | Construct | Terciles |
|---|---|---|
| Conceptual vs calculational* | 1,50,22,31,33,40,10 | H,H,H,H,I,I,L |
| Difficulty | 2,32,38,54,53 | H,I,I,I,L |
| Looks and descriptiveness of problem | 36,21,20,30,55 | H,H,I,L,L |
| Close to everyday life (on continuum scientific/technological/personal)* | 52,25,46,12,3 | H,H,H,I,L |
| Mathematical requirements* | 15,17,27 | H,H,I |
| Openness of problem | 9,35,41 | I,L,L |
| Superficial properties – text length | 13,5,19 | H,L,L |
| Difficulty – time investment | 8,34,44 | L,L,L |
| Enjoyment (perceived personal enjoyment)* | 7,45,28 | H,H,I |
| Curricular order – school-relevant content* | 6,47 | H,H |
| Curricular order – necessary knowledge for solving problem | 37,16 | L,L |
| Developing mental problem representation (sketching/imagining situation) | 49,24 | H,L |
| Perceived learning gain* | 29,39 | H,H |
| Complexity | 4,14 | L,L |
| Proximity to person (persons are actors) | 51,26 | H,L |
| Analytical* | 23 | H |
| Miscellaneous | 11,18,42,43,48,56 | I,I,L,I,H,I |

Note: The construct numbers refer to the table in Appendix 2. The construct-categories marked with an asterisk are retained for further analysis.

# 3 Discussion

## 3.1 School-Related Content Knowledge

It is important to note that the concept of school-related content knowledge (SRCK), as described in section 2.1, is one of many concepts for the teacher-specific content knowledge. There are multiple concepts already for the subject of mathematics, developed for instance in Kiel (Dreher et al., 2018) and Michigan (Ball et al., 2008). Multiple descriptions of the content knowledge that is specific for teachers can be found for physics too (see for an overview Woitkowski and Borowski (2017)). Almost parallel to this project, the project Profile-P and Profile-P+ (Professionswissen in der Lehramtsausbildung Physik [Professional knowledge in physics teacher training]) developed their conception of this category (Riese et al., 2015; Vogelsang et al., 2019), also based on earlier work by Riese (2009) and Woitkowski et al. (2011). The conceptualisations described in their work however remain subject-specific and lack the incorporation of the syntactic structure of knowledge, as described by for instance Schwab (1978). SRCK as used in this dissertation (section 2.1) combines the existing conceptualisations in mathematics and physics and includes both the substantive and syntactic structures of knowledge.

### 3.1.1 Is SRCK still subject-specific?

SRCK is presented as a cross-disciplinary approach - at least for the subjects involved. Whether this new approach is generally accepted by all disciplines remains the question. The now included syntactic structure of knowledge (knowledge about the discipline) includes aspects described in the nature of science or the nature of history (Lederman, 1992; Günther-Arndt, 2006). Can the same be said about for instance the *nature of languages*? Is this part of the teacher-specific content knowledge of an English or French teacher? Another aspect of SRCK that might be difficult to apply in the setting of language teacher education is the knowledge of concepts or the knowledge to adapt complexity meaningfully, since it is not always possible to connect the university content knowledge to a school context. It would be interesting to hear the perspective of someone in this field on this issue.

### 3.1.2 SRCK in Action

The existing conceptualisations of the teacher-specific knowledge in physics and mathematics described above are almost exclusively used as part of a content knowledge test (see for instance Sorge et al., 2017; Vogelsang et al., 2019). The three-dimensionality of content knowledge could be demonstrated with these test (Riese, 2009; Enkrott et al., 2018), giving the category that is described by SRCK some empirical validity.

What might be of more interest to this dissertation is the implementation of SRCK for the development of learning opportunities for pre-service teachers. Within the project PSI-Potsdam, multiple studies were undertaken that used the SRCK-conceptualisation to develop learning material with the aim to connect school knowledge with the university content knowledge taught at universities.

Reitz-Koncebovski et al. (2018) used SRCK to develop mathematics lectures for two mathematics courses for pre-service primary school mathematics teachers that do what is described above: connect the school knowledge with the university knowledge. They base their lectures on four principles, derived from SRCK:

> (1) pursue fundamental ideas: vertically through the curriculum from elementary up to higher education, and horizontally through different fields of mathematics,
> (2) explicitly teach knowledge about concepts and cross-connections,
> (3) bring pre-service teachers into the learning situation of school students and encourage them to reflect on their experiences with respect to their future teaching work,
> (4) exemplify the procedural nature of mathematics.
>
> (Reitz-Koncebovski et al., 2018, p175)

Evaluations at the end of the lectures point at an acceptance by students: some students see that these lectures are relevant to them for their future career. However, a comparison with previous versions of the same lecture where SRCK was not used in the design of the lecture was not available: unclear is whether there was a real effect of using the facets of SRCK.

Güleryüz (2018) developed a course for the subject Lifeshaping-Ethic-Religious education based on some facets of SRCK, especially the subfacets 'Concepts can be reinforced with examples' and 'Concepts can be used for the structuring of knowledge' (see figure 1 in section 2.2). Evaluations of this course show a twofold image: students seem to realise that the contents taught can also be used beyond their studies (i.e. in their later profession as teacher), but when directly asked about the school relevance of the topics, the students tend to give a neutral answer. Güleryüz (2018) explains this by pointing at the diverse groups of students: what can be seen as relevant to the group of bachelor students, who will later be teaching at secondary schools, can be seen as irrelevant for the group of master students that will become primary school teachers. Again: it is unclear what the results of the evaluation would be for a course that was not developed using the facets of SRCK.

In a study that is similar to the one described in this dissertation, Hermanns (2018) developed problems based on the facets of SRCK for tutorial sessions (part of a course on organical chemistry) for pre-service chemistry teachers. These students attend the same lectures as the chemistry major students, but discuss their homework problems in separate tutorial sessions. A typical problem could for instance be a problem where chemistry-technical difficulties with a problem should be identified or a problem where the use of subject-specific terminology was central to the problem. The problems that were developed seem to be accepted by students as problems that can improve their SRCK-level (as self-assessed by the students). The study was however not done blindly: the students knew which problems were supposed to have this effect, which could influence their choices. Next to this result, a higher activity of the students when working on the problems was observed by the author, which can be seen as a positive result.

In a teaching-learning arrangement for pre-service biology teachers, which was conceived on the basis of SRCK, pre-service teachers first reactivate their ideas on a specific topic within biology in order to check their appropriateness for their use within biology teaching. Subsequently, their ideas will be used in learning tasks for the content related de- and reconstruction of school materials (Woehlecke et al., unpublished). They found that students can apply SRCK with instructive support through guiding questions, even though individual aspects including the identification and description of the possible consequences of technical reductions are still found to pose challenges.
A different concept was developed for another biology course for pre-service biology teachers (Glowinski et al., 2018). In an additional seminar to the lectures of the course animal physiology, students were asked to analyse the content knowledge of the lectures with respect to the core-concepts and core-principles (Loughran et al., 2012). Their task is, among others, to determine the concepts central to the course and to answer the question: 'why should secondary school students learn this?'. This can be traced back to the facet of SRCK 'knowledge about concepts and their application in the respective subject'. Another direct connection to SRCK is the question to which extent the teacher's knowledge should go beyond the knowledge to be taught in school. An evaluation of the seminar showed that students showed a great learning progress and an adequate understanding when asked about the potential of concepts as structuring elements in biology. Students wish that instructors would actively refer to concepts in lectures, because "If concepts were present in the lecture, they were not reflected as such"(Glowinski et al., 2018, p116). The students highly appreciate this new seminar and express the desire for more courses where connections between CK and PCK are made.

As described above, SRCK can be used for the development of learning opportunities that are specific for pre-service teachers. While the first results look promising, it is unclear whether or not these learning opportunities based on SRCK lead to an increase in the level of SRCK with the students and whether or not it leads to an increase in the perceived relevance of the topics taught.

## 3.2 Using Physics Problems based on SRCK

In the second paper of this dissertation (section 2.2), a positive effect of the physics problems that are based on SRCK is described: problems that are based on SRCK are perceived as more relevant by pre-service physics teachers than the regular, quantitative problems.

### 3.2.1 Perceived Relevance of the SRCK-Problems

Concerning the results in the second paper, it must be noted however that although in both courses the pre-service teachers on average rate the SRCK-problems as more relevant than the physics majors do, the difference in the average rating by pre-service teachers between the SRCK-problems and the regular, quantitative problems is only statistically significant in Experimentalphysik 2. This course entails topics that are more distant to school knowledge than Experimentalphysik 1. Our hypothesis is that this is the reason why the SRCK-problems are perceived as more distant than the regular, quantitative problems in Experimentalphysik 2 and why we do not see this as clearly in Experimentalphysik 1. In the final weeks of Experimentalphysik 1, more school-distant topics were discussed. SRCK-problems are seen as more relevant in these weeks too. This hypothesis has however not been tested: the "distance to school physics" has also not been quantified or clearly described, which is necessary for a thorough analysis. Does the distance to school physics really have an influence on the perceived relevance of the SRCK-problems on that subject or is there some other causal relation? Since only one SRCK-problem was used every week, it could also be that these specific problems for these weeks worked really well and the SRCK-problems in the other were weeks were not designed that well. Developing these problems is not always easy: some turn out to be better than the others. A repeat study with a larger collection of SRCK-problems could clear this issue.

For the larger part of Experimentalphysik 1, the problems based on SRCK were not seen as more relevant than the regular, quantitative problems. The distance (or better: closeness) to school physics has already been given as a possible explanation. Another hypothesis is that the problems based on SRCK do have an effect, but not only on the perceived relevance of these particular problems but also on the perceived relevance of all problems. What if the SRCK-problem shows the students the relevance of the particular topic and by doing that, also increases the perceived relevance of the other (i.e. regular, quantitative) problems on the same topic? A possible way to control for this effect would be a set-up in which a group with problem sets containing only regular problems is compared to a group with a mixture of the different problem types. This would however lead to a different exam preparation for both groups: they would not have worked on the same problem types. Since the exam contains problems from all problem types, one group would not be prepared well enough for the exam, making this design not a viable one.

Another possible explanation for the lack of difference in perceived relevance between the regular and SRCK-problems by pre-service teachers is that these students might not have a clear enough image yet of what kind of knowledge they need as a teacher; the facets of SRCK describe this knowledge. We expect the problems based on these facets to have a higher perceived relevance by these students, but we do not know whether they understand that the knowledge needed to solve these problems will be beneficial to them. They are after all only first and second semester students that did not have a course in physics education yet; the first of these courses starts in the third semester. So can we expect them to identify the knowledge they need? An interview study with these students might give an answer to this question.

### 3.2.2 Conceptual Problems in General

The results of the second paper show that the problems based on SRCK are seen as more relevant than the regular, quantitative problems. They are however not perceived as more relevant than the conceptual problems that are *not* based on SRCK. Do the facets of SRCK have an influence of the perceived relevance of the problems or is it just the fact that the problems are conceptual that leads to a higher perceived relevance? This question led to the interview study described in the paper in section 2.3. But apart from that, this result is already very interesting: conceptual problems are seen as more relevant to pre-service physics teachers than regular, quantitative problems. By including these problems in problem sets, the problem sets can be made more relevant to these students. This would of course benefit these students. For the physics majors, it does not really matter. They see all problem types as just as relevant to them. As discussed in section 2.2, this could be because these students do not really have a clear image of their future career to begin with (which was used in the wording of the question of perceived relevance). A study by Henning et al. (2012) for instance shows that physics problems that were made more authentic had no effect on the motivation of physics majors, but did have a positive effect on that of the non-physics majors that also worked on these problems. It could be that physics majors do not really care about the problems they work on when it comes to motivation and perceived relevance.

The increased focus on conceptual problems in the courses could not only have an influence on the perceived relevance of the pre-service teachers and therefore on their motivation, but also on the problem solving skills of both groups of students: Crouch and Mazur (2001) report improved results on problem solving skills (tested with the Mechanics Baseline Test by Hestenes and Wells, 1992) in a course where conceptual knowledge is emphasized in comparison to a traditional course without this emphasis.

### 3.2.3 Difficulty and Acceptance of the Conceptual Problems

The physics majors - just as the pre-service teachers - do see a difference in the difficulty of the different problem types. They rate the conceptual problems as easier than the regular, quantitative problems - although this difference is not always statistically significant. This could be an issue for the acceptance of the

problems by the instructors of the courses: they do not want to 'lower the standards' by introducing easier problems. It is important to note here that the rated difficulty of the problems by the students is a perceived difficulty: the students do not know yet whether a problem which they think was easy was actually solved correctly by them. Does perceived difficulty correlate with real difficulty? According to Bratfisch et al. (1972), it does. Their study was however done using a intellectual performance capacity test and is not physics-specific. For mathematics problems for chemistry students, Kimpel (2018) also found a correlation between real and perceived difficulty.
A study that was aimed at physics (to be more precise: electromagnetics) however shows that students working on conceptual problems on this topic could very confident give wrong answers (Leppavirta, 2012), hinting at a rather low correlation between perceived and real difficulty. It is therefore difficult to say whether this lower perceived difficulty as reported by the students really tells something about the real difficulty.

One quality control mechanism adopted in our study was that the problems had to be accepted by the instructors; the problems found their way into not only the weekly problem sets but also into the final exams of both courses. This is dependent on the instructors however: different instructors at for instance a different university could maybe have issues with the lower perceived difficulty of the conceptual problems. It is therefore difficult to say whether other instructors would come to the same conclusion regarding the implementation of these problems.

The fact that conceptual, qualitative physics problems also make it into a final exam is very important, since

> students are likely to ignore whatever changes one makes to the format or content of a class *unless these changes are reflected on the examinations* (Mazur, 2014, p26)

Implementing the conceptual problems into the exams shows the students that the instructors think these problems are important to them.
Instructors might however have issues with grading conceptual problems, since answers in the form of essays might take more time to grade. A grading scheme proposed by Mazur (2014) that mirrors the review practice of scientific journals might be of benefit here: 'Publish as is' for instance (where the answer is perfect or nearly perfect) might lead to three points and 'reject' (where the answer has little or no relevance to the question) to zero points (Mazur, 2014, p219).

### 3.2.4 Generalizability of the Results

The results shown in section 2.2 and discussed above are the results from a study at one university with one group of students: most of the students from Experimentalphysik 2 attended Experimentalphysik 1 in the same year. Repeating the study with a different group or at a different university could of course lead to different results. For universities that have a comparable curriculum as the university of Potsdam, there is no reason to assume that the results will be different there. A different curricular setup could however have an influence: it could be for instance that the students at this hypothetical university already had their first experiences with PCK-courses in their first semester (something that is recommended by the DPG (DPG, 2014)). The SRCK-problems could have a bigger impact at this university, since the pre-service teachers might already have a better idea of what it means to be a teacher.

## 3.3 Problem Properties that Increase the Perceived Relevance

The results of section 2.2 (pre-service physics teachers tend to see the conceptual problems as more relevant to them than the regular problems) led to the study described in section 2.3. The question that is central to this study is: how do students determine whether a problem is relevant to them? What kind of constructs do they use to come to this decision? These constructs might give us insight into the problem properties that influence perceived relevance and might make it therefore easier to develop problems that are perceived as more relevant. Until now, no research - known to the author - has been done on properties of physics problems that have this effect.

### 3.3.1 Results from the Interview Study

The study gives us six problem properties that have an influence on perceived relevance. As expected, the 'conceptualness' of a problem is one of these properties: more relevant problems are often the conceptual ones. Calculational problems are seen as less relevant. This is reflected too in the property 'mathematical requirements': problems with lower mathematical requirements are less relevant. This might again lead to the conclusion that easier problems are seen as more relevant, but this conclusion is too easy: both 'Difficulty' and 'Complexity' were generated as construct-category, but these construct-categories show an intermediate to low effect on the perceived relevance. Easier problems are not automatically more relevant. The more advanced mathematics - that might not be necessary to solve physics problems in secondary school - is however seen as less relevant.

Another interesting problem property that emerged from this study is 'Close to everyday life'. A problem closer to everyday life is seen as more relevant. A physics teacher should be able to make relations between physics and daily life: a problem that is close to everyday life would therefore be seen as more relevant to the pre-service teachers, because they might know that they need this skill later in their career.

The problem property 'Curricular order' (where a problem is more relevant when the content is more relevant to school) can be seen as an obvious one: If the content is more school-relevant, the pre-service teachers see these problems as more relevant to them. This is the same mechanism we have put forward as an explanation for the results of section 2.2: when the content is more distant to school, a difference in perceived relevance between the regular, quantitative problems and the conceptual problems based on SRCK is observed. Without this distance, the pre-service teachers do not see a difference between the problem types: all the problems are already relevant to them, because the content is clearly school relevant. When the distance to school physics is greater, then other problem properties (e.g. conceptual or not) are needed to increase the perceived relevance.

### 3.3.2 Problem Properties and SRCK

A connection between the problem properties that have a positive influence on perceived relevance and the facets of SRCK is somewhat difficult to make. The construct-category 'Analytical' (where a problem that is more analytical, i.e. a given situation has to be analysed, is more relevant) can however be connected to the facets of SRCK: most of the SRCK-problems require the students to analyse a given situation. A hypothetical mistake made by a student should for instance be analysed, or a explanation in a schoolbook should be judged with respect to physical correctness. This construct-category contains only one construct however, which means that the evidence here is not that strong. A study with a different design might lead to more connections with SRCK.

For the current study, only seven students were interviewed. A higher number would probably lead to more constructs being generated which could lead to a reinforcement of the 'Analytical' construct-category or maybe to a new construct-category that has a different connection with SRCK.

Not only a bigger sample could have an influence on the results, but also a larger number of problems that is discussed. In the current study, three SRCK problems were discussed. That means that not all the facets of SRCK that were used in the study in section 2.3 to generate problems were also used for the problems that were discussed in the interview study. More students and more problems could lead to clearer results. The repertory grid technique, although very useful to elicit personal constructs, is however a technique that is very time-intensive. More problems to discuss means that the interviews take even longer which would probably lead to less students being interested in taking part in the study.

### 3.3.3 Explicit Reasons

In this study we tried to find implicit -'gut feeling'- reasons for perceiving a problem as relevant. A follow-up to this study could be an analysis of the interviews with the goal to find the explicit reasons: what do students say when they are asked why a problem is relevant to them? It is interesting to find out whether there will be any differences with the implicit reasons. It could be that a construct-category exists that did not show up in the current study.

### 3.3.4 A Quantitative Follow-up

After analysing the results of this study, a short follow-up study was done. The question in this study was whether we could also identify the problem-properties that have a influence on relevance in the problems that were used in Experimentalphysik 2. After rating all the problems with respect to the six problem properties, we can then look for a correlation with their perceived relevance from the data of the study in section 2.2: the ratings of the students in that semester. Can we for instance see that problems that are rated high on the 'Analytical'-scale are really more relevant?

This study turned out to be difficult. We found no correlation between the six problem-properties and the perceived relevance of the problems. A cause of this might be that *personal* constructs were used to create the construct-categories. These construct-categories were then used to create a manual that could be used to rate the problems with respect to the problem properties. A research assistant and the author then used this manual to rate all the problems. Both raters might however have a different view on what is meant by 'Analytical' of could have a different view on the mathematical complexity of the problem: the research assistant -a master student with more mathematical experience- could for instance have a different opinion on what 'low mathematical requirements' are. This problem could have led to a missing relation between the problem properties and the relevance of the problems as rated by the students during the semester. An improvement of the manual that was used to rate the problems with respect to the six problem properties could lead to a different result.

## 3.4 Summary and Implications

### 3.4.1 Summary

The perceived irrelevance of content knowledge can be seen as one of the reasons behind the motivational problems for pre-service physics teachers. In order to increase this perceived relevance, conceptual problems that are based on the knowledge and skills that are part of the content knowledge that is specific for teachers have been developed. This content knowledge category has first been further developed on the basis of theoretical work and previous definitions. *The many examples of the implementation of courses for pre-service teachers on the basis of SRCK show that SRCK is a workable model to develop instructional material,* although there is not a lot of evidence on the effect of the newly designed material on perceived relevance of the course material by the students.

The results of this study show that physics problems that are of the conceptual type are perceived as more relevant by pre-service teachers than regular, quantitative problems. The physics content should however have a distance to the physics that is discussed in school for this effect to be seen. Without this distance, no difference between the problem types is found. This means that the SRCK-problems 'work' for Experimentalphysik 2 - since the content of this course is

more distant to the physics in school - but only partly for Experimentalphysik 1 since the content that is part of this course is close to the content discussed in school. However, this explanation remains a hypothesis, since the "distance to school physics" has not yet clearly been defined.
The SRCK-problems do not seem to be the solution for the problem of perceived relevance in the first semester. There is however no distinction between specific courses in the literature on the lower perceived relevance by pre-service teachers: students perceive the content of university courses as not always relevant, but unclear is to what courses this low perceived relevance refers. Maybe the students do not have a problem with the perceived relevance of Experimentalphysik 1 to start with, because of its proximity to school physics. This could have been determined with the help of a questionnaire at the end of the course. A simultaneous intervention with the help of the SRCK-problems would then influence the results.

This dissertation is focussed on increasing the perceived relevance with the help of SRCK. The problems based on SRCK can also have another influence, next to this increased perceived relevance: they can improve the teacher-specific content knowledge. This would lead to a qualitative improvement of the teacher education that does not necessarily go through the motivation of the students. Future work could focus on this effect, for instance with the help of a test that focuses on the teacher-specific content knowledge of students. A (physics-specific) content knowledge test based on SRCK has however not been developed yet.

The conceptual problems that are based on SRCK do not have a higher perceived relevance than conceptual problems that are not based on this model. This would mean that the problem properties derived from the facets of SRCK do not really have an influence on the perceived relevance. It is important to point out here that there is no *statistical significant* difference between these two conceptual problem types. The mean relevance score for the SRCK-problems is higher than that of the other conceptual problems - on both courses -, but this difference is not statistically significant. It would therefore be interesting to see what the results would be if the study was repeated with a larger set of problems or at multiple universities: maybe we can see a statistical significant difference then.

This difference between the two conceptual problem types can also be seen when we compare the two groups of students with each other: The pre-service teachers perceive the SRCK-problems as more relevant to them than the physics major students do. The same can be said for the other conceptual problem type. However, in both Experimentalphysik 1 and 2 the effect size is clearly bigger for the SRCK-problems than the other conceptual problems. *Introducing conceptual problems increases the perceived relevance for pre-service teachers. It makes the problem sets more relevant to them than for the physics majors and more relevant than a problem set containing only regular, quantitative problems. This effect is bigger for the SRCK-problems.*

It is important to note that for physics major students the problem type does not seem to matter: they do not perceive a difference in relevance between the different problem types. However, *both groups can profit from the introduction of conceptual problems since they can have a positive influence on their problem solving skills*

The interview study leads to *six problem properties that have a positive influence on the perceived relevance of physics problems.* One of them is the 'conceptualness' of the problem, which reinforces the results from the main study. The facets of SRCK only show up in one of the six problem properties - a problem in which a given situation has to be analysed is seen as more relevant. Since the differences in perceived relevance between the conceptual problem types are not large, it would be surprising to see more properties that can be traced back to SRCK here. Other problem properties that increase the perceived relevance of physics problems by pre-service teachers are their closeness to daily life, a lower level of mathematical requirements, the curricular order of the content (closer to school means more relevant) and perceived learning gain: when students have the idea that they learn something by solving the problem, the problem is seen as more relevant to them.

Even though the conceptual problems are perceived as less difficult by both the pre-service teachers and the physics majors, the problems were accepted as important for both groups by the instructors of the courses. Difficulty could also not be identified in the interviews as a problem property that would influence perceived relevance. Together with the weak relation between perceived and real difficulty of problems this means that *the lower perceived difficulty of the conceptual problems should not be a reason not to implement conceptual problems into problem sets.*

### 3.4.2 Improving Physics Teacher Education

In order to make the problems used in content knowledge courses more relevant to pre-service physics teachers - which would increase their motivation, improve their learning and prevent drop-out - it is recommended to use problems that are qualitative, conceptual problems. Although there is no empirical evidence for it, the problems should preferably be based on the facets of SRCK since this would theoretically also improve the knowledge and skills that they would use as a teacher. Other problems that might increase the perceived relevance of these problems are problems that:

- have a context that is close to everyday life
- have a lower level of mathematical requirements
- include a situation that has to be analysed
- give the students the idea they learn something
- have a content that is close to school physics.

This does however not mean that problem sets should only contain these types of problems: regular, quantitative problems are also important for both pre-service teachers and physics majors. A mixture of conceptual problems and regular, quantitative problems could increase the perceived relevance of the problem set on average while at the same time improve their problem-solving skills. An implementation of these problems would lead to an overall improvement of the physics teacher education: not only would it have a positive, quantitative effect but also a positive qualitative effect.

### 3.4.3 Physics Education *sui generis*?

In a perfect world, the physics teacher education would - according to the DPG - be set-up as a *sui generis* study: physics teacher education *of its own kind* (DPG, 2006, 2010). This would mean that the pre-service teachers would not attend the same courses as the physics majors: they would attend courses that are aimed specifically at them. How does one design these courses? For the problems that will be used in these courses, the results show that conceptual problems have a positive impact on the perceived relevance of the problems and should therefore be used. Conceptual problems based on SRCK have the same impact on the perceived relevance but would theoretically also improve their teacher-specific content knowledge and should therefore also be used. My recommendation would be to use the model of SRCK for developing the lectures or seminars too. Not to base them solely on SRCK, but to make a combination of parts where the university knowledge is taught and parts where is reflected on this knowledge with the help of SRCK: to make the important connections between university knowledge and school knowledge.

## 3.5 Contribution to Literature

### 3.5.1 A New Model for the Teacher-Specific Content Knowledge

In the first paper (section 2.1) a new conceptualisation and operationalisation of the teacher-specific content knowledge, part of the professional knowledge of teachers, is described. Other than existing models, this model includes both the substantive and syntactic structure of knowledge. The existing models are models that are subject-specific, designed for either physics or mathematics. The proposed model of school-related content knowledge however is a cross-disciplinary approach, at least for the subjects involved in the study. Next to the description of the model itself, ideas for using the model to improve learning arrangements for pre-service teachers are proposed.

### 3.5.2 An Intervention Study where Conceptual Problems based on SRCK are used to improve the Perceived Relevance

In the study described in section 2.2, an intervention study to test the effect of the use of the SRCK-model for developing physics problems on the perceived relevance by pre-service teachers is described. Several existing studies on the teacher-specific content knowledge tend to use their model to develop tests for this content knowledge dimension. But until now, no study has used such a model to adapt learning arrangements and test them in an intervention study. Similarly, the importance of the relevance of instructional material has been described often, but there are only a few studies that describe interventions to increase the perceived relevance of instructional material, none of them for the specific group of pre-service physics teachers.

The study of the difference in perceived relevance between conceptual (qualitative) and calculational (quantitative) problems is another contribution: no study known to the author has compared these two problem types with respect to perceived relevance. The results of this study are very interesting: in situations where the content is more distant to school physics, conceptual problems are seen as more relevant to pre-service teachers.

### 3.5.3 A Study on Relevance from the Perspective of Students

Relevance has often been studied, including the perceived relevance of learning material. Usually, these studies are done from the perspective of the researcher or the instructor. New to this field are the results of the perceived relevance of physics problems from the perspective of the students: why do students think that a problem is relevant to them? Since relevance is described as a 'personally meaningful connection to the individual', it makes sense to research relevance from the perspective of this individual (here: the student). The resulting problem properties are also new to the field: there is no research known to the author that studies properties of physics problems with respect to perceived relevance.

Although the repertory grid technique we use is by itself not new, its application in studying the properties of physics problems is new to the field.

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# List of Abbreviations

- ARCS - Attention, Relevance, Confidence, Satisfaction
- CK - content knowledge
- DPG - Deutsche Physikalische Gesellschaft (German physics society)
- PCK - pedagogical content knowledge
- PK - pedagogical knowledge
- SRCK - school-related content knowledge

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