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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.

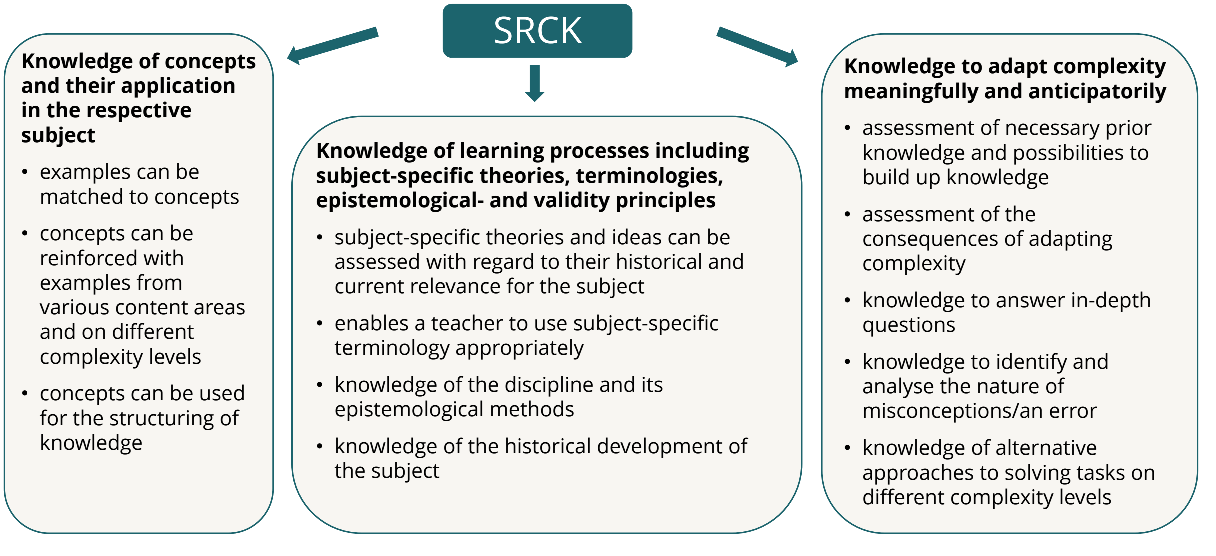

Figure 1: Facets of School-Related Content Knowledge (Woehlecke et al. 2017).

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.

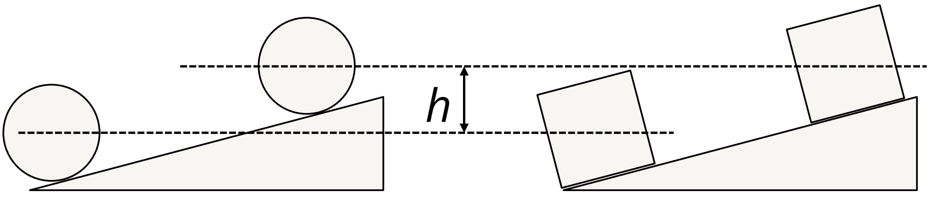

Figure 2: Two objects on a frictionless plane. Which object arrives at the bottom with more total kinetic energy? When the cylinder is rolling without slipping, the block cannot glide without friction on the same plane. Problem adapted from Mazur (1997).

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: • What are the physical consequences of the reduction? • What information was left out? • In which situations will this be problematic? • In which situations will this not pose any problems? • What is the connection between the reduced school knowledge and the university knowledge? (bottom-up approach) • How can you reduce the university knowledge to arrive at the school knowledge? (top-down approach) Given is a solution to a problem by a hypothetical student. The student should answer one or more of the following questions: • What approximations were made by this student? • Are these approximations correct? • Are there situations in which this approximation cannot be made? • [...]

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: • Are the statements/solutions incorrect? Why? • What physical mistakes were made by this student? • How can one improve the statement/solution? Given is incorrect information from a textbook. The student should answer one or more of the following questions: • What are the mistakes? • 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.

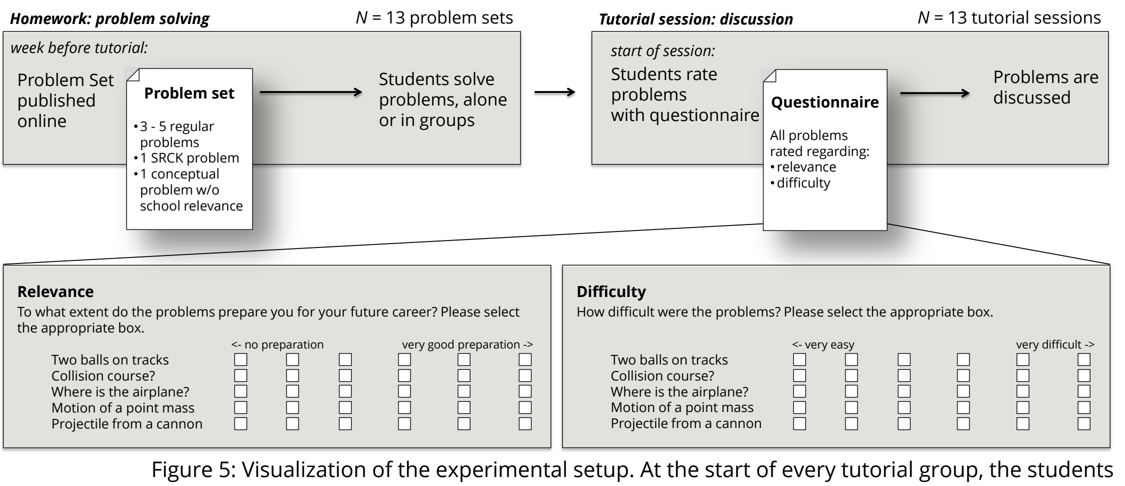

Figure 5: Visualization of the experimental setup. At the start of every tutorial group, the students were asked to rate all the problems on the problem set with regard to (among others) perceived relevance and difficulty.

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; ω^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.

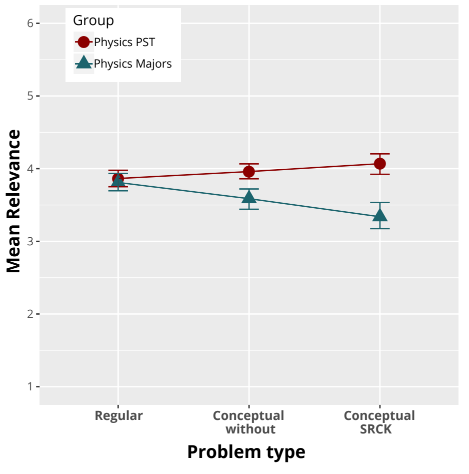

Figure 6: Perceived relevance of problems by problem type by physics pre-service teachers and physics majors for the course "Experimental Physics 1". The error bars show the 95 % confidence intervals.

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; ω^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.

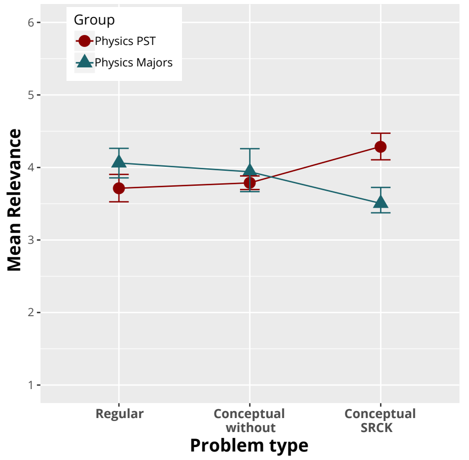

Figure 7: Perceived relevance of problems by problem type by physics pre-service teachers and physics majors for the final third of the semester for the course "Experimental Physics 1".

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).

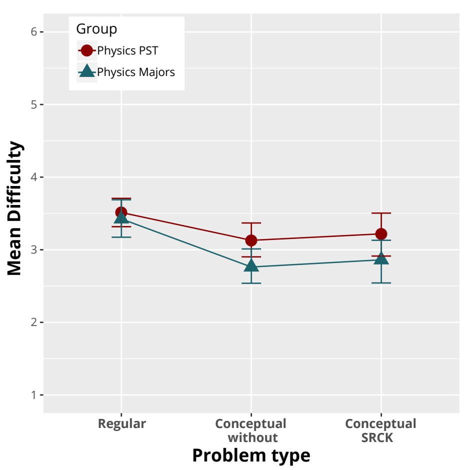

Figure 8: Reported difficulty of problems by problem type by physics pre-service teachers and physics majors for the course "Experimental Physics 1".

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, $F(2,74) = .098$; $p = .91$.

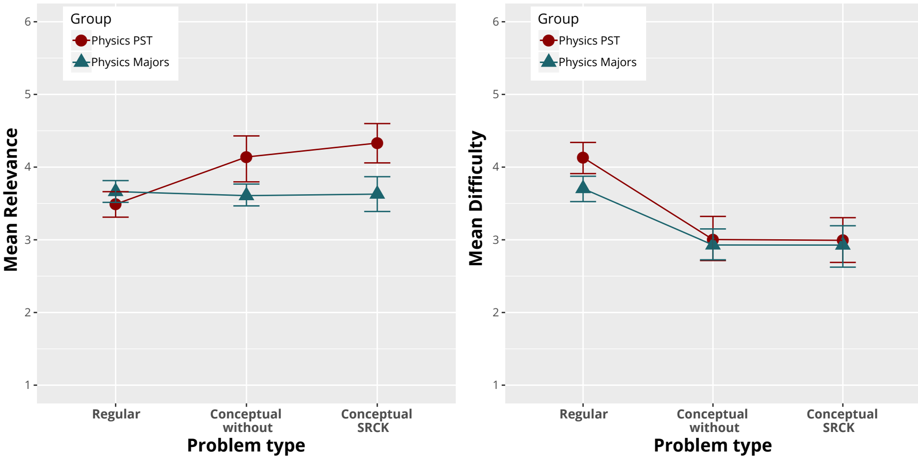

Figure 9: Perceived relevance of problems by problem type by physics pre-service teachers (top left) and physics majors (top right) and reported difficulty of problems by physics pre-service teachers (bottom left) and physics majors (bottom right) for the course "Experimental Physics 2".

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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