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A TOOL TO SUPPORT LECTURERS' COURSE DEVELOPMENT AT INTRODUCTORY UNDERGRADUATE LEVEL IN PHYSICS

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Abstract. *With more diversified student groups entering the university, the development and planning of courses become more pedagogically challenging. In earlier studies, a validated tool, content representation (CoRe), has been used in teacher education to help pre-service teachers identify and promote pedagogical content knowledge in limited teaching sequences. In the present research the aim is to explore whether CoRe, when applied to an introductory university course in physics, can (i) promote the pedagogical content knowledge of the course as a whole and (ii) serve as an operative tool to identify problematic areas or areas that need further development in the course. The CoRe tool is based on given questions to be answered in relation to the "big ideas" of the course. In the present research, the questions have been answered by a lecturer and by using a content analysis of the answers several categories of development could be identified. For a specific category, the tool also provided information about what kind of development was necessary. The conclusion is that CoRe has a potential to be of service at higher education level, it can be applied to parts of a course as well as to a course as a whole, and it may provide a useful tool to help a lecturer in the development and planning of a course.*

Key words: *content representation; course development; physics education; university level, pedagogical content knowledge.*

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Introduction

The interest among young people, especially in Europe and Japan, for careers in the area of mathematics, science and engineering is declining (OECD 2006; Osborne & Dillon 2008; Sjøberg & Schreiner 2010). To meet the demands from the industry and public sectors regarding engineers and other professionals trained in technology, presumptive students for science and engineering studies must be looked for more broadly and in new groups. The result is that nowadays students in science and engineering often have more diverse study backgrounds, and not seldom they come from homes without traditions of higher education. As a lecturer one must take this into consideration when planning courses. The pedagogical toolbox of the lecturer must therefore be extended to meet broader demands and needs from the students.

The development and planning of a course involves considering the aim, selection of content, teaching methods and examination methods from a holistic perspective but also an understanding of the students' pre-knowledge (Ausubel, Novak, & Hanesian, 1968; Mestre, 2001). Over the years extensive works and descriptions have been published about how to develop physics courses in order to achieve better conceptual understanding, problem solving and experimental skills among students (McDermott & Redish, 1999; Mestre, 2001; Wieman & Perkins, 2005). Examples include the development of practical laboratory work, often computer aided (Finkelstein et al., 2005), the use of gadgets (Duncan, 2006) and methods for conceptual teaching (Mazur, 1997), teaching sequences for specific topics (Linder & Fraser, 2006), multiple representation and multimodal teaching (Fredlund, Airey, & Linder, 2012; Tang, Tan, & Yeo, 2011), examinations (Wieman, Rieger, & Heiner, 2014) and the evaluation of teaching quality (Wieman, 2015).

Another useful tool for the development and planning of a course is content representation (CoRe) (Loughran, Mulhall, & Berry, 2004). It has been used as a conceptual tool for the development of pre-service teachers' awareness and thinking in their planning of science teaching (Nilsson & Loughran, 2012), where CoRe can be used to identify pedagogical content knowledge (PCK) (Shulman, 1986, 1987).

An entrance to CoRe are the "big ideas" that can be identified in relation to a specific scientific topic to be taught. This means that the big ideas are to be interpreted based on the specific teaching situation and may stand for different things when teaching for example about a closed electric circuit or gravitation. Mapped against each "big idea" are eight questions and by providing answers to these the teacher describes why a particular idea is important, what the difficulties for the students might be, which teaching methods are appropriate and so on. See Table 1 below or the Appendix in Nilsson and Loughran (2012) for further clarification.

Table 1. The eight questions in the CoRe template from Loughran et al. (2004).

1. What do you intend students to learn about this idea?
2. Why it is important for students to know this?
3. What else do you know about this idea (that you do not intend students to know yet)?
4. What difficulties/limitations are connected with teaching this idea?
5. What is your knowledge about students' thinking which influences your teaching of this idea?
6. What other factors influence your teaching of this idea?
7. What teaching procedures will you use and what are the particular reasons for using these to engage with this idea?
8. What specific ways do you have of ascertaining students' understanding or confusion?

CoRe has successfully been used as a methodological tool to make pre-service elementary teachers aware of their PCK (Mavhunga & Rollnick, 2013; Nilsson & Loughran, 2012; Padilla & Garritz, 2011) when planning, teaching and evaluating a selected topic in science. The general character of the questions in the CoRe table provides a basis for a broader use of the tool. However, CoRe as a tool for pedagogical development has not been reported to have been applied by science lecturers e.g. at introductory undergraduate level to a wider content such as a course as a whole.

Shulman (1987, p. 15) makes no content limitation for pedagogical content knowledge, but describes it as "the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful". Hence, in the present research, by constructing a CoRe table that includes the stratification of big ideas, it is argued that a pedagogical focus can be applied not only to a specific scientific topic but also to the content of a course as a whole. In this context, it may also be noticed that a big idea approach is quite common in science and has been used in connection with specific topics at compulsory school (Harlen et al., 2010), higher education levels (Moore, 2003) or framing for a complete school curriculum (Levrini et al., 2008), covering great parts of the whole subject of physics.

Focus of the Research

If the CoRe table can be used on the level of a course as a whole it may provide a simple method to help a lecturer identify course related issues to be developed and strengthened and in this way facilitate the achievement of deeper knowledge and better skills for the diverse groups of students entering the universities today. The aim of the present research is hence to apply this method to the wider pedagogical content of a physics course at introductory undergraduate level and, in this sense, explore the limitations of CoRe. In particular, the research addresses the two questions: (i) Can CoRe be used to promote knowledge of the pedagogical content of a course as a whole? and (ii) Can CoRe serve as an operative tool to identify problematic areas or areas that need further development in a course and thereby help the lecturer to develop the course? From this it can hence be decided whether the CoRe table can provide a supporting tool for a lecturer in the pedagogical development and teaching of a university course.

Methodology of Research

In order to test the applicability of CoRe, this exploratory research was conducted qualitatively with the CoRe table as a tool for an interview and the answers given to the questions in the CoRe table were then subjected to a content analysis in order to classify the content into different categories. Two researchers, of which one also was a teacher, participated. A general introductory physics course at undergraduate level has been selected. This basic level course is available to students applying for engineering programs, but who lack formal competence in science. The course covers essential parts of classic physics, including mechanics and an introduction to modern physics. It is a 15 ECTS credits course (European Commission, n.d.) and is taught over one semester in parallel with a course in mathematics, also at introductory undergraduate level. This also put the time span for the research to one semester. The teaching of the course mainly consists of lectures, problem-solving exercises and laboratory work. At the time when this research was performed, the course recruited some 90 students, who were divided into three separate groups. One of the authors (the lecturer/author) taught one of these groups and a colleague, not participating in the research, the other two groups. The lecturer/author had taught this specific course on one occasion prior to the research. The other author had never taught the course, but both authors had over 20 years of experience of teaching physics at university level, from introductory level up to advanced level.

Procedures and Data Collection

In the first stage of the research the table constituting the CoRe template was completed. The table consists of a top row for presenting the big ideas describing the course content and columns for each idea with the questions (1 – 8) for the teacher to reflect on and answer, see Table 1. In the CoRe table, these questions are given while the big ideas must be formulated for the specific course. The table was filled in by the two authors in collaboration, as described below. This was done before the course started and based mainly on the experience of the lecturer/author from teaching the course at a previous occasion.

For the present course, the six learning outcomes in the course syllabi turned out to provide appropriate answers to the first question in the CoRe template: "What do you intend students to learn about this idea?". The number of learning outcomes in the course syllabi then fixes the number of big ideas to six. This gives an indication of the importance of well written learning outcomes that combined cover the course as a whole.

With the learning outcomes as a guide, and based on his own experience, one of the authors then formulated the six big ideas for the course. The ideas were then presented to the lecturer/author, who accepted these formulations as agreeable with his own view of what the big ideas in this course were. These ideas are presented in Table 2.

The author also interviewed the lecturer/author using the remaining seven questions from the template as the basis for a structured interview (Bryman, 2012). These questions can be found in Table 1. The interview took the form of an active dialogue creating knowledge in collaboration (Holstein & Gubrium, 2004), with a summing up for each question. Therefore, based on this dialogue the interviewing author proposed a summarized answer, which the lecturer/author could then adjust or reformulate. The lecturer/author always decided whether the answer matched his view or not.

Two follow-up interviews were subsequently held with the lecturer/author; once during the course and once at the end of the course. These follow-up interviews were based on the content in the CoRe table and mainly dealt with the identification of the categories but also, to some extent, with the actions that needed to be taken in order to deal with identified difficulties and intended developments in the course.

Table 2. The big ideas constituting the content of the course.

1.	One can make a systematic description of the physical world
2.	The systematic description contains models of relationships that can be applied and used for calculations
3.	The plausibility of a calculation can be assessed by rough estimate
4.	One can develop knowledge by experimenting
5.	Tools like computer software can facilitate an understanding of the data
6.	Physics is part of our society

Data Analysis, Ethics and Authenticity

The content of the table was analyzed by the interviewing author and interpreted by means of a conventional content analysis (Hsieh & Shannon, 2005). This form of content analysis goes beyond a counting and sorting of words and amounts to examining the text in order to classify the content that represent similar meanings and sort it into categories. This is a crucial part of the research as the PCK is not only concerned with a specific topic as in the original use of the CoRe methodology. Instead, the focus here is to investigate whether the CoRe table can help teachers at introductory undergraduate level to develop deeper insights into their teaching practices and thus contribute to the development and planning of the course as a whole.

Therefore, the aim of the content analysis has been to find key issues related to teaching, with a special focus on the difficulties or areas for development from the lecturer's perspective. Based on the content in the CoRe table, six different categories, or main themes for development, were identified for this course.

Care was taken to fulfill the ethics considerations stated by the Swedish Research Council (Hermerén, G., Gustafsson, B., & Pettersson, B., 2011). No other persons were involved or exposed but the authors. Furthermore, for interpretive research methods the authenticity and plausibility of the data must be considered (Walsham 2006). As there was no obvious reason for the interviewed teacher to manipulate or give false answers and as the interviewing author has an extensive teaching experience, the answers could immediately be face validated (Holden, 2010) and must be considered both authentic and plausible. Questions may also be raised about the generalization of the results, but as the main purpose of the research is to investigate the possibility of using the CoRe table as a tool for course development, the generalization of the results is not considered to be an issue for this research. The results are also to be understood as unique for the particular course to which this method is applied.

Results of Research

In the process of answering the questions in the CoRe template it was found that these questions cover important issues regarding the selection of teaching content, the teaching level and methods and why these had been chosen by the lecturer.

Identified Categories

The six identified categories describing problematic areas or areas for development in the course are described in Table 3. The category *Mathematics* primarily emerged from the first two big ideas: 1. One can make a systematic description of the physical world and 2. The systematic description contains models of relationships that can be applied and calculated. Questions 4 and 6 were relevant here, 4. What difficulties/limitations are connected with teaching this idea? and 6. What other factors influence your teaching of this idea? These questions elicited the following answers in the CoRe table related to mathematics:

> "Linked to the mathematical concepts that are also new for the students" (first idea, question 4).
> "Especially mathematics, mathematical skills for calculations" (second idea, question 4).
> "Need to apply mathematics and understand its concepts" (first idea, question 6).
> "Must adapt to their mathematics skills. Requires dialogue with teachers of mathematics courses" (second idea, question 6).

Table 3. Categories that describe areas for further development. The corresponding ideas and questions in the CoRe table are also listed.

Category	Description	Idea: Question
Mathematics	Use mathematics in physics modelling and problem solving.	1:4, 1:6; 2:4, 2.6, 5:3
Teaching support	Expand multimedia support in teaching situations, for example use YouTube and demonstrations.	1:7
Individual support to students	Due to a more diverse student enrolment some students need individual support in the learning process and time needs to be allocated for this.	2:5, 2:7, 2:8, 3:7
Technical support in laboratory work	Due to a more diverse student enrolment some students need support to a greater extent in handling the technical equipment.	5:2
Oral and writing support	To see oral presentation and writing not as a domain outside physics but as a tool to reach understanding.	4:4, 4:6
Connections between physics and everyday life	Support the students to see and include physics as a part of everyday life	6:2, 6:5, 6:8

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Hence, it was found that this category included an essential link between mathematics and physics in a university physics course, implying that students must have access to mathematical knowledge and also competence in applying mathematics to make calculations based on the physical models.

The category *Teaching support* was based on one single statement in the table:

"[The lecturer] might refer to YouTube clips as support for the students" (first idea, question 7).

The reason why this single statement motivates a category emerged in the follow-up interviews when the lecturer described how the teachers had advised the students to watch a few chosen YouTube clips in order to facilitate an understanding of the two concepts kinetic energy and heat energy. During the interview the lecturer/author also described how this part could be developed and included as part of a term paper which also was implemented later in the course.

The need for more time for learning in class appears in the third category: *Individual support for students*. This category emerged from the second and third ideas and the last two questions (7 and 8) in Table 1 but also from question 5: What is your knowledge about students' thinking which influences your teaching of this idea?

A statement in this category related to the idea that the plausibility of a calculation can be assessed by estimation was:

> "It is difficult for students to understand how to do this in such a short time" (third idea, question 7)

Other answers pointed to the need for a dialogue with the student at a more individual level in order to support learning:

> "Be prepared to 'steer' the problem-solving process" (second idea, question 8)

The fourth category *Technical support and laboratory work* emerged from the idea 5. Tools such as computer software can facilitate understanding of the data. This idea motivates the use of computer-aided support in laboratory measurements and analyses. In the follow-up interviews problems related to this appeared, such as some students tend to see the equipment as a black box, they may have difficulty interpreting graphs and may not realise when a measurement is a failure. Time is also a limiting factor in the laboratory in that students have to finish in the scheduled time.

The fifth identified category was *Oral and writing support*. This relates to the idea that through experiments one can develop knowledge. The responses to the questions in the CoRe table connected to difficulties and other factors affecting teaching include:

> "The ability varies in the oral and written presentation [among the students] [and] report writing." (the fourth idea, question 4)

This is seen in the compulsory laboratory reports and also in the term papers that the students write as part of the course and oral presentations.

The category *Connections between physics and everyday life* arose from the idea that physics is part of our society. Here the lecturer/author described how important it was for students to regard physics as a basis for different technological applications, but that they often found this difficult to grasp and reflect on.

Discussion

In previous studies (Mavhunga & Rollnick, 2013; Nilsson & Loughran, 2012; Padilla & Garritz, 2011), a CoRe scheme for pedagogical content representation and identifying pedagogical content knowledge has been described in connection with teacher education. The CoRe tool has then been used to help pre-service teachers in their planning of limited teaching sequences in science teaching.

The aim of the present research is to examine whether the CoRe scheme to develop pedagogical content knowledge, can be applied to a wider content such as a university physics course at introductory undergraduate level and, in this sense, explore the limitations of CoRe. The purpose has not been to further describe details for the course development in the different identified problematic areas nor to further analyze the results of such development.

The main focus has been to answer the two questions (i) Can CoRe be used to promote knowledge of the pedagogical content of the course as a whole? (ii) Can CoRe serve as an operative tool to identify problematic areas in the course and/or areas that need further development? When applying the CoRe tool to a university course, some problems arise that have to be addressed and it is not obvious to what extent CoRe is well suited for the analysis of the pedagogical content of such a course.

The CoRe table consists of a number of already given questions and a number of big ideas that must be formulated and provided by the user of this tool. The usefulness and the outcome of the CoRe scheme is thus highly dependent on the formulations of these big ideas. This then, constitutes a major challenge when applying the CoRe tool to a university course. In the present research, it is suggested that the big ideas may be derived from the learning outcomes of the course syllabi which then have to be reformulated to statements that express their content in terms of basic ideas. Clearly, the proper formulations of the learning outcomes then become crucial for a successful analysis of a course by using the CoRe table.

A further issue that arises is connected with the answers to the eight questions that are given in the CoRe table and to what extent these answers can be used to identify specific problematic areas of the course. In this study, a conventional content analysis has been used to classify content that represents similar meanings into categories. As the answers and also the identified categories are dependent on the content knowledge possessed by the lecturer, it is not likely that the answers will add anything that is not already known. However, the use of the CoRe table organizes this knowledge systematically and clearly points to different pedagogical aspects of the course.

With the big ideas derived from the learning outcomes and the lens of the CoRe table then focused on the course as a whole, it has been found that the given set of questions in the CoRe table together with the big ideas of the course helped to uncover and describe in some detail the pedagogical content of the course. In addition, for the studied course, this tool also helped to reveal six main, often problematic, areas for further pedagogical development.

The problematic areas identified in this research could then be investigated further. Many of these areas are well known to experienced lecturers and have already been identified in earlier research (see below) as general problems in physics education. Thus, it is found that support for course development and suitable actions in some of the specific areas identified by the CoRe tool are already at hand through research literature.

For example, it is commonly observed by lecturers that mathematics is a problematic area in connection with physics, especially for modelling and problem solving (Larkin & Reif, 1979; McDermott & Redish, 1999; Adams & Wieman, 2006; Redish, 2016) which commonly constitute central parts of a physics course at university level. The lecturer/author developed this observation and had discussions with the lecturers in the parallel mathematics course and together with them planned for a just-in-time delivery of some relevant mathematical topics.

The solution put forward in this research for mathematical topics to be delivered just-in-time for application in physics is similar to earlier developments of structuring physics courses from a just-in-time philosophy (Novak, Patterson, Gavrin, & Enger, 1998; Page et al., 2013). This can be seen as a pre-stage to the flipped class room (Berrett, 2012; Tucker, 2012). The introduction and use of YouTube clips in the investigated course may also be the beginning of a change that eventually may turn the course into a flipped classroom activity.

In connection with the category Oral and writing support it is found that a fundamental aspect of learning science is to understand and use the correct vocabulary, or conceptual language (Lemke, 1990). This needs to be practiced in problem solving, report writing and oral presentations. Lemke (1989, p 139) formulates it as "students´ ability to restate a sentence or passage in their own words is the surest sign of comprehension". Even though no special measures were taken for this course at this moment, suggestions can be found in the literature for developing this domain in physics teaching (Jewczyn et al., 2013).

Conclusion

The results describe both a condition for the use of CoRe as well as a limitation regarding its usefulness. The questions which are part of the CoRe table are both general and penetrating in character and may hence be suitable to analyze the pedagogical content of a science university course. However, a condition for the usefulness of this tool is well formulated, user supplied, big ideas that properly describe the different aspects of the basic content of the course. Hence, the character, extensiveness and depth of the resultant pedagogical content knowledge are to a large extent dependent on the formulations of these big ideas which then also may limit its usefulness. In addition, the quality of the answers that the user provides to each question in the CoRe table also set a limitation

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on the usefulness of the CoRe tool.

If the big ideas are derived from the learning outcomes in the course syllabi, as is suggested in the present research, the learning outcomes must contain a precise and well delimited description of the different aspects of the course preferably with no overlap and they must cover the whole course. This then gives a proper ground to formulate relevant big ideas of the course. Based on these big ideas, the eight questions in the CoRe table then serve as means to uncover and describe different aspects of the pedagogical content of the course.

Concerning the first of the two research questions, whether CoRe can be used to promote knowledge of the pedagogical content of the course as a whole, the results indicate that the CoRe table may provide a simple and useful tool to uncover and describe the pedagogical content of a science university course as a whole, at least at undergraduate university level.

Concerning the second research question, whether CoRe can serve as an operative tool to identify problematic areas in the course and/or areas that need further development, the results indicate that the CoRe table may indeed be used as a means to help identify areas of importance for the development and planning of a physics course at undergraduate level.

The questions in the CoRe table and the answers to these questions for each big idea provide a tool for the lecturer to systematically reflect on and categorize the course´s pedagogical content. From this a meaningful analysis may be conducted that can be useful for course development and also possible to connect to research topics in physics education.

If the big ideas are derived from the learning outcomes in the course syllabi, the CoRe tool may help the lecturer to identify different skills that the students need to develop in order to meet the learning outcomes of the course. Due to its structure and the formulations of the big ideas, the CoRe table facilitates the mapping of a course´s problematic areas and can hence be useful both to design courses and for pedagogical development.

The new application of the CoRe tool presented in this paper may be of interest to try out on other courses with other learning outcomes. These are then expected to generate other, course specific big ideas and reveal other, course specific categories or areas for course development. An area for future research may be to describe and implement the pedagogical development and activities identified by using the CoRe tool, in line with suggestions from educational research, to find out if this leads to increased student learning and better fulfilment of the course´s learning outcomes.

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