

DESIGNING A TEACHER QUESTIONNAIRE TO EVALUATE PROFESSIONAL DEVELOPMENT IN MODELLING

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LEMA is an international project to design a professional development course for modelling. In order to measure the effects of the course, an evaluation questionnaire was developed and pilot tested. Based on theoretical background about modelling, this paper outlines the challenges of the design process, presents reliability and validation data, and exemplifies each scale with a few sample items.

Keywords: Modelling, professional development, international approach, design of an evaluation questionnaire, empirical study

INTRODUCTION

Researchers, practitioners and policy makers in mathematics education agree that educationist aim should be to enable students to apply mathematics to their everyday lives (PISA, OECD, 2002) and contribute to the development of active citizenship. However, modelling is still rare in day-to-day teaching around Europe. LEMA (Learning and Education in and through Modelling and Applications) is a trans-national European Project¹ that tackles the problem at teacher level by developing a common course of professional development in mathematical modelling. The aim of this paper is to provide an approach to the evaluation of professional modelling development in different national contexts and settings that is theory-based and driven by analysis of needs.

Teachers' knowledge and beliefs about the nature of the subject, their views on how to educate the subject and their self-efficacy beliefs about teaching the specific subject influence how they design or select tasks, plan, implement and evaluate their lessons (e.g. Brickhouse, 1990). Thus, to successfully implement mathematical modelling in their actual classroom practice, teachers need to (amongst others) (1) know the key concepts of mathematical modelling, (2) change their beliefs about the nature of mathematics education (if not appropriate for modelling), and (3) increase their awareness of their own competency to implement mathematical modelling in their actual classroom practice (self-efficacy).

THEORETICAL BACKGROUND

Mathematical modelling means applying mathematics to realistic, open problems. There are many descriptions of modelling processes (Blum & Niss, 1991; Kaiser-

¹ Partners of LEMA: Katja Maass (Coordinator) & Barbara Schmidt, University of Education Freiburg, Geoff Wake, University of Manchester, Fco. Javier Garcia Garcia, University of Jaen, Nicholas Mousoulides, University of Cyprus, Ödon Vancso & Gabriella Ambrus, University of Budapest, Anke Wagner, University of Education Ludwigsburg, Richard Cabassut, IUFM Strasbourg. The project is founded by the EU.

Messmer, 1986). They vary according to the described modelling cycle, the relevance given to the context and the justifications seen for modelling in mathematics lessons (Kaiser & Shiraman, 2006). In this study, we follow the description of the modelling process in PISA (Prenzel et al., 2004), albeit restricting it to context-related problems.

Modelling competency is the ability to carry out modelling processes independently. It comprises the competencies to carry out the single steps of the modelling process as well as competencies in reasoning mathematically and metacognitive modelling competencies (Maaß, 2006). Similar distinctions have already been made by Kaiser and Blum (1997) and indirectly by Money and Stephens (1993), Haines and Izard (1995) and Ikeda and Stephens (1998) in setting up assessment grids.

Modelling lessons: A trans-national project, which aims at developing a common, research-based professional development intervention for Europe, faces the challenge presented by partners having different theoretical backgrounds related to the teaching of modelling situated in their different national contexts. Thus, we sought to identify where common ground and indeed differences might be used to enrich such a project. For example, the English partner adopts a socio-cultural approach – drawing particularly on ideas of the development of learner identity and using Cultural-Historical Activity Theory (CHAT) (Engestrom & Cole, 1997). Research of the Spanish team, on the other hand, relied upon the Anthropological Theory of Didactics (Chevallard, 1999). Finally, the German partner's position is located in the international discussion on modelling and focuses on authentic tasks showing the usefulness of mathematics.

Drawing upon all of these approaches, a theory-based design emerged as follows: The German partner provided descriptions of the modelling cycle and focused on authenticity, both aspects being used to design tasks and support didactical development in the classroom. With relation to the Spanish partner, authenticity can also be seen in the search for questions that are crucial for students as social individuals. The English partner's perspective that engaging with mathematics can be considered a social activity provides teachers and researchers with a range of new learning and pedagogical models.

In short, the theoretical approach – related to the teaching of modelling – used in this study is a synthesis of a variety of theoretical backgrounds. This allows for and ensures that combined expertise guided this trans-national project.

Professional development of teachers: When considering teachers' competencies in teaching, we follow Krauss et al. (2004) and Shulmann (1986) by distinguishing professional knowledge (content knowledge, pedagogical content knowledge, pedagogical knowledge), beliefs, motivational orientation and competencies in reflexion and self-efficacy.

Empirical studies of teachers' professional development (e. g. Tirosh & Gerber, 2003; Wilson & Cooney, 2002) show that professional development interventions lead to changes if the courses are long-term, with embedded phases of teaching and reflexion, and if further factors which might have an impact on teachers' possibilities

to teach modelling (such as the framework, the head of the school, parents, teacher's own beliefs) are taken into account.

Teachers' beliefs about the nature of mathematics and its education are believed to have a major impact on if and how a teacher employs innovation in everyday teaching. According to Pehkonen and Törner (1996), beliefs must be understood here as being composed of a relatively lasting subjective knowledge of certain objects as well as the attitudes linked to that knowledge. Beliefs can be conscious or unconscious, whereas the latter are often distinguished by an affective character.

Kaiser (2006) showed that innovations required by the curriculum are interpreted by the teacher in such a way that they fit into his or her existing belief system. Grigutsch, Raatz & Törner (1998) classified beliefs about mathematics into various aspects: the aspect of scheme (fixed set of rules); the aspect of process (problems are solved); the aspect of formalism (logical, deductive science); and the aspect of application (important for life and society).

Teachers' self-efficacy beliefs in this context can be described as teachers' beliefs in their capabilities to organize and execute mathematical modelling activities in their planning and classroom practice (see Bandura, 1997, Bandura, 2006). Self-efficacy is a future-oriented belief about the level of competence a person expects he or she will experience in a given situation. Self-efficacy beliefs influence thought patterns and emotions that enable actions and effort for reaching goals and persist in the face of adversity. "The self-assurance with which people approach and manage difficult tasks determines whether they make good or poor use of their capabilities. Insidious self-doubts can easily overrule the best of skills" (Bandura, 1997, p. 35).

Considering pedagogical content knowledge about modeling as an external measure of learning success, both beliefs about the nature of mathematics and the education of mathematics and self-efficacy beliefs touch the individual's own perception and motivational aspects potentially relevant for application in the actual classroom setting.

DEVELOPMENT OF THE COURSE

Analysis of needs: In order to design a suitable professional development course for teachers, we first conducted a needs analysis to assess teachers' mathematical beliefs, their use of tasks, and their attitude towards given modelling tasks. Altogether, $N = 563$ teachers from the partner nations participated in the needs analysis. The measurement instrument included items about beliefs, which were rated on a 4-point rating scale ranging from 1 (strongly disagree) to 4 (strongly agree). Additionally, items related to the tasks teachers use (e.g. tasks practising basic skills vs. problem solving tasks) and three concrete modelling tasks were given to the teachers (all related to the same context, but differing in their task openness). Teachers were asked how likely they were to use each task and to justify their response.

Results revealed that teachers gave high rating scores for belief items in the process dimension (e.g. mathematics allows you to solve problems: $M = 3.49$) and the application dimension (e.g. mathematics is useful in everyday life: $M = 3.5$). Conversely,

they gave relatively lower scores for the formalism and scheme dimension (e.g. mathematics is a fixed body of knowledge: $M = 2.44$). However, when asked which tasks they would most likely use in their lessons, the majority selected “tasks that practised basic skills” ($M = 3.48$) as opposed, for example, to “problems with other than one solution” ($M = 2.38$). Accordingly, when asked if they would use any of the given modelling tasks, the closed tasks proved to be very popular, while the more open versions drew less enthusiasm. Commonly cited detractors for the open tasks were perceived difficulty and class time constraints.

In terms of designing an evaluation questionnaire, the analysis of needs also made clear that the more related the questions are to day-to-day teaching (e.g. related to concrete tasks), the more objections become evident.

The course of professional development: Based upon the findings of the needs analysis, the following considerations were given particular attention: First, we addressed the teachers’ concerns and difficulties in using modelling tasks by providing further information about the benefits inherent to each modelling task. We also addressed different ways to assess and support students in their development of modelling competencies.

Based on the needs analysis and the synthesis of various theoretical backgrounds, we developed the professional development course into five key aspects (modules):

(1) *Modelling*: To implement modelling in lessons, teachers need background information about this concept (sub-modules: What is modelling? Why use it?) (Blum & Niss, 1991).

(2) *Tasks*: When it comes to planning lessons, teachers need to learn how to select appropriate tasks for their students and anticipate the modelling outcomes. An emphasis was placed on authentic tasks (sub-modules: Exploring, Design, Classification and Variation) (see e.g. Maaß, 2007, Burkhardt, 1989, Galbraith & Stillman, 2001, Kaiser-Meßmer, 1986)

(3) *Lessons*: Research has shown that group work, discussion and working independently all support the development of modelling competencies (sub-modules: Methods, Using ICT, Supporting the Development of Modelling Competencies, Exercising Mathematical Content Through Modelling), (see e.g. Tanner & Jones, 1995, Maaß, 2007, Ikeda & Stephens, 2001)

(4) *Assessment*: If modelling is implemented in lessons, it also has to be evaluated. Assessment should be used not only for grading but also for supporting learning through feedback (Williams & Black, 1998) (sub-modules: Formative Assessment, Summative Assessment, Feedback).

(5) *Reflexion*: As outlined above, reflexion about implementation in lessons and dealing with challenges is crucial for the success of professional development courses (sub-modules: Implementation, Challenges).

Piloting: This course was piloted and evaluated in all 6 partnership countries. Piloting took place in 2008 and comprised 5 days. Implementation, however, was quite different. For example, in France the training was given as a one-block course in January 2008, addressing teachers teaching students aged 6-8 years. In Spain, the course contained two blocks in April and May. Finally, in Germany the course consisted of 5 separate days from January to November and addressed primary and secondary teachers at the same time.

The main question was how such a course, which was piloted under different conditions and in different national contexts, could be evaluated. We did not consider students for evaluation because this seemed to be almost impossible given the huge variety of students concerned (age 6 to 16) and the given national contexts. Focusing on teachers, we used questionnaires and interviews and exemplary videos. Questionnaires and interviews give insight into teachers' point of view and so provide information about teachers' intentions and thus about necessary preconditions of the change of day-to-day teaching. Here, we will focus on the teachers' questionnaire.

DESIGN OF THE QUESTIONNAIRE

Instrument Development and Field Testing: The questionnaire was prepared to assess all teachers taking part in the course (6 countries, 10-40 teachers per country). To measure possible knowledge gains and belief changes we implemented a pre-post-control-group design. The development and testing of the instrument took place in 5 steps.

Step 1: Establishing rationales guiding the design: First, items should mirror the theoretical background and key-aspects of the modules of the professional development. Thus, the questionnaire sought information about the pedagogical content knowledge, beliefs, and self-efficacy about mathematical modelling as well as beliefs about mathematics and its education. Items covered these categories and all five modules. Second, considering the target group and their understandable preference for a short questionnaire, our aim was to find a balance between a reasonable length and what would still provide a reliable assessment. Third, careful guidelines were developed to improve compliance in filling out the questionnaire and the quality of the implementation of the questionnaire (i.e. we provided information regarding the necessity of an evaluation for further improvement and emphasized that it was the course and not the teachers that was being evaluated).

Step 2: Procedure and materials preparation: Considering the first rationale of Step 1, the scale construction was based on established scales wherever possible. The scale of belief items about the nature of mathematics and its education was based on Grigutsch, Ratz and Törner (1998). Items were related to four aspects of beliefs (see above). Learners rated their beliefs on a 5-point scale, ranging from strongly disagree to strongly agree.

Based on Bandura's method for measuring self-efficacy beliefs (Bandura, 2006), we designed a self-efficacy scale assessing efficacy beliefs related to modelling on a

100-point scale, ranging in 10-unit intervals from 0% ("cannot do at all"), to 100% ("highly certain can do").

For the assessment of the pedagogical content knowledge, we decided to use questions in an open format, the main consideration here being sensitivity for measuring knowledge provided in the course. Teachers were supposed to show their active knowledge, as this is probably the knowledge which they use in teaching. The open questions used for this knowledge assessment were rated by two independent, trained raters considering the amount and quality of arguments based on an expert solution.

Step 3: First Item Refinement – A Small Tryout: First, we conducted a small pilot study. The tryout instrument was administered to a group of 7 teachers and 3 teacher trainers. In addition to filling out the questionnaire, participants were asked to comment on the items they found misleading or difficult to understand. Consequently, items that were mentioned as being misleading were adapted. Items where the answers of teachers showed a lack of focus were reformulated. Considering the target group, the initial questionnaire was too long (time needed > 60 min). Thus, we analyzed the questionnaire for time-efficiency and possibilities to omit certain items. For example, the first questionnaire contained an open item referring to beliefs about the different areas where mathematics can be useful. As this was not directly linked to the content of the course, we omitted this item due to time vs. diagnostic value considerations. The first question "What is modelling?" was moved to the end, because some teachers were unable to answer it and therefore became discouraged right from the beginning.

Step 4: Second Item Refinement – Expert Questioning: To improve the content validity of the items, the questionnaire was submitted to 10 modelling experts, each with more than 5 years' teacher education. They were asked to evaluate whether the item statements would adequately deliver information about the proposed modelling curriculum.

As a result, certain questions were reworded, for example the rather general "What is modelling?" became "Name as many characteristics about modelling tasks as possible". In addition, it was moved back to its original location at the beginning of the questionnaire, so that examples of modelling tasks given in other parts of the questionnaire would not influence one's response to this question. To address possible feelings of discouragement among participants, we decided to provide the following introduction: *Whether or not you have already heard of or know anything about mathematical modelling and modelling tasks, it does not matter here. We simply want to know the starting point for the teacher training course.* This introduction also served the purpose of informing participants that they were not going to be tested. Another useful lesson gained from the modelling experts was to clarify the intention of the items related to beliefs by focusing on the beliefs about mathematics education and to omit items related to beliefs about mathematics itself. Again, the questionnaire was shortened. For example, the original questionnaire included three suitability rat-

ings of different tasks, that took almost 20 minutes to answer but only comprised three single Likert-type scales accompanied by short comments.

Step 5: Testing and Item Selection: After conducting the above-mentioned revisions, we conducted a pilot study with prospective teachers, including 24 experts in modelling and 23 novices in modelling, to simulate pre- and post-testing. This testing targeted the following research questions:

1. How reliable is the pedagogical content knowledge-scale, the beliefs about modelling scale and the self-efficacy scale?
2. How good is the interrater-agreement between two independent raters scoring the open format knowledge questions?
3. Is the developed scale able to differentiate between novices (without experience in modelling and experts (in modelling)?

The first two questions about psychometric properties of the scales can be answered as follows. The reliability of the aggregated pedagogical content knowledge score was good (Cronbach's $\alpha = .83$). Forty percent of the open format questions were co-rated by a second rater (for 18 of the 47 participants), and the interrater agreement, shown by the intraclass correlation coefficient (ICC) was good ($ICC_{2,2} = .91$). Thus, only one rater coded the rest of the protocols. The reliability of the aggregated beliefs about modelling scale was good (Cronbach's $\alpha = .87$). The reliability of the aggregated self-efficacy belief score was high (Cronbach's $\alpha = .96$).

To answer the third question of whether the scales were able to differentiate between novices and experts we used a one-factorial ANOVA to analyze the data. An alpha level of .05 was used for all statistical tests. As an effect size measure, we used partial η^2 , qualifying values $<.06$ as small effects, values in the range between .06 and .13 as medium effects, and values $>.13$ as large effects (see Cohen, 1988). Results of the analysis of variance showed that the experts had significantly higher knowledge scores about modelling than the novices, $F(1,41) = 23.22$, $p < .001$, $\eta^2 = .36$ (large effect). The analysis also showed that the experts had significantly higher scores related to beliefs than the novices, $F(1,34) = 13.97$, $p < .001$, $\eta^2 = .29$ (large effect). Last, the analysis revealed that the experts had significantly higher self-efficacy beliefs about modelling than the novices, $F(1,35) = 6.68$, $p < .014$, $\eta^2 = .16$ (large effect).

These findings provide evidence that lead to the conclusion that also from a quantitative point of view, the developed questionnaire shows good reliability and construct validity. We also surveyed 8 practicing teachers with the questionnaire and found that descriptively they scored close to the novices concerning modelling skills.

In order to address concerns about further shortening the questionnaire, items that did not seem absolutely necessary for measuring the pedagogical content knowledge, beliefs about mathematical modelling or self-efficacy were screened for discriminatory power and difficulty. In other words, if the items were too general or too easy, they

would not be able to measure improvement. The final questionnaire contained the following sections: biography, beliefs about mathematics lessons, pedagogical content knowledge and beliefs related to modelling, and self-efficacy. The following examples provide a closer look at some of these sections:

Beliefs: We used items based on Grigutsch, Raatz and Törner (1998) but with a focus on school mathematics, for example – each of them with a 5-point Likert scale.

	School mathematics in my lessons from my point of view as a teacher	Strongly disagree				Strongly agree
5.1.1	School mathematics is a collection of procedures and rules which determine precisely how a task is solved.					
5.1.2	School mathematics is very important for students later in life.					
5.1.3	Central aspects of school mathematics are flawless formalism and formal logic.					

Pedagogical content knowledge: Within this section we addressed the following aspects: modelling, reasons for and against modelling, tasks, methods and assessment. All items were related to a corresponding modelling task because, as the needs analysis clearly showed, being as concrete as possible was paramount to getting valid results. Most of the questions had an open format. For example:

Imagine you are teaching children whom you regard the right age for this task. The following 5 questions are all related to the task below and all connected with each other.

It is the start of the summer holidays and there are many traffic jams. Chris has been stuck in a 20-km traffic jam for 6 hours. It is hot and she is longing for a drink. How long will the Red Cross need to provide everyone with water?

Imagine you are teaching children whom you regard the right age for this task.	not very likely				very likely
6.1 Please x one to show how likely you are to use this type of task	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

6.2 Give as many reasons as possible (pros and/or cons) and mark them as such (+/-).

To evaluate the concept of assessment, a student's solution was given to the teachers and they were asked to provide written feedback. Further, teachers were asked also about methods they would use in a specific situation, all in relation to the task given.

(7) **Self-efficacy:** The scale was based on Bandura (2006) and included the following sample items that had to be rated on a 100-point scale, ranging in 10-unit intervals from 0% ("cannot do at all"), to 100% ("highly certain can do"):

I feel able to teach mathematical content using a modelling approach.

I feel able to develop detailed criteria (related to the modelling process) for assessing and grading students' solutions to modelling tasks.

FINAL NOTES

This paper exemplified the development process of designing a questionnaire evaluating the success of a professional development course on mathematical modelling. The greatest challenge was accommodating the participants' preference for a short questionnaire and evaluating the multifaceted aspects of the course as accurately as possible.

The results of the evaluation will be finalized in September 2009. The final evaluation questionnaire is available on request from the first author.

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