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Working with teachers on inquiry based learning (IBL) and mathematics and science tasks

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This paper reports on teachers' experiences from and their evaluation of a teacher professional development event arranged in connection with the European PRIMAS[1] project. Inquiry-based learning (IBL) and analysis of 'appropriate' mathematics and science tasks were the focus of this professional development programme, as these are said to increase students' interest of and attainment levels in mathematics and science education. The data are anchored in observations and feedback/evaluations from a two-day session with a selected group of teachers, where the focus was on mathematics and science task analysis, in order to develop an awareness and knowledge of characteristics of mathematics and science tasks. Results show that during the event teachers developed a deeper understanding of task characteristics, of constraints and affordances of particular IBL tasks; and they reasoned more critically with respect to particular features and selected tasks more carefully. This, it is argued, lies at the heart of productive professional development and the enhancement of teacher knowledge in and for teaching.

Introduction

The curriculum for Norwegian compulsory school (Kunnskapsdepartementet, 2006) and national guidelines for primary education (Kunnskapsdepartementet, 2010a) highlight the importance of an «exploratory» and «curiosity driven» approach to learning, and it appears that these approaches are used far less than desired (e.g. Rocard et al., 2007). In order to address this situation several projects at European, national and local level have been funded where the focus is on exploratory and curiosity-driven approaches to learning. The literature contends that this will increase students' motivation and commitment to science and mathematics. It is also suggested that such approaches would be an effective form of teaching, giving students a better understanding of natural science and mathematics.

Based on findings from TIMSS (Hiebert et al., 2003) it is reported that high achieving countries engage students more frequently in rich mathematics and science activities than lower achieving countries. In particular, it is claimed, students (in high achieving countries) are presented with rich and open problems that require them to make connections between different mathematical and scientific ideas. Working with rich mathematics and science curriculum materials to create learning opportunities

[1] www.primas-project.eu

for pupils, and at the same time to develop mathematical knowledge for teaching is an important part of the work of teaching. In this study we investigate teachers' experiences from and evaluation of a teacher professional development event arranged in connection with the European PRIMAS project. The research question for this study is: How do teachers' develop a deeper understanding of mathematics and science tasks and inquiry based approaches to teaching and learning?

Theoretical background

Large scale international comparative studies in mathematics and science (TIMSS; PISA) have shown that Norwegian pupils perform relatively poorly and at a significantly lower level than expected (e.g. Grønmo & Onstad, 2009; Kjærnsli, Lie, Olsen, & Roe, 2007; Kjærnsli, Lie, Olsen, Roe, & Turmo, 2004; Lie, Kjærnsli, Roe, & Turmo 2001; Lie, Brekke, & Kjærnsli, 1999). There has also been a noted decrease in recruitment to mathematically demanding and science related studies (Schreiner, 2008). These facts have influenced the Government to increase the emphasis on sciences and mathematics education (e.g. Kunnskapsdepartementet, 2010b).

Efforts to enhance mathematics and science education, it is argued, should concentrate on primary and secondary education, as students' declining interest in mathematics and science can be related to the way subjects are taught at those levels (Rocard et al., 2007). IBL has also proved its efficacy (at both primary and secondary levels) in increasing children's and students' interest and attainments levels while at the same time stimulating teacher motivation (Rocard et al., 2007). As recommended in the strategy document «Science Education Now – A Renewed Pedagogy for the Future of Europe» (Rocard et al., 2007, p. 3), «improvements in science education should be brought about through new forms of pedagogy: the introduction of inquiry-based approaches in schools».

IBL processes in mathematics and science education

Inquiry based learning (IBL) is a teaching pedagogy that already in the 1950s appeared in the western world (Anderson, 2007). Today it is used in several disciplines. In science it is called Inquiry Based Science Education (IBSE) internationally, while the most used Norwegian term is exploratory work, «utforskende arbeid» (Knain & Kolstø, 2011). In mathematics teaching, the education community often refers to Problem-Based Learning (PBL) rather than to IBSE (Rocard et al., 2007). There are many different definitions of IBL (Knain & Kolstø, 2011). The term 'inquiry' refers to a variety of processes and ways of thinking, which are said to support the development of new content knowledge (Flick & Lederman, 2006). Hofstein and Lunetta (2004) point out that 'inquiry' covers both the method researchers are working on, as well as how students learn important characteristics about science, by suggesting ideas, explaining and defending the allegations by evidence from their own research. Further, Carlsen and Fuglestad (2010) clarify that inquiry is not one method, one procedure or one set of rules, but an attitude: to be curious and 'investigative' in new situations and with new challenges. A common misconception is that IBL is similar to doing experiments or practical work in the classroom. This is perhaps related to the fact that IBL has great similarities with the scientific way of working. The similarities with Nature of Science

(NOS) also shine through in Linn, Davis and Bell's (2004) definition of inquiry, which is also used in the Rocard-report (Rocard, et al., 2007):

> Inquiry is the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments. (Linn, Davis, & Bell, 2004, p. 4)

The term inquiry is thus an approach that implies that students develop new ideas and thoughts from their own experiences. According to Wells (1999, p. 121) inquiry is «a willingness to wonder, to ask questions, and to seek to understand by collaborating with others in the attempt to make answers to them».

It can be said that IBL is an essential ingredient of a good education and classroom culture. When IBL processes are introduced, the classroom culture should be characterized by open-mindedness, dialogue and shared ownership. Valued outcomes from such a culture are inquiring minds, that are prepared for an uncertain future and life long learning, and have good understanding of the nature of science and mathematics. Questions/tasks within an IBL-culture are often open, with multiple solution strategies, and experienced as real and/or scientifically relevant. Students pose questions, inquire and collaborate.

Teachers guide students through their learning process, they value and build upon students' reasoning/scaffolding and connect to students' experience..

In terms of student learning, the Rocard-report (Rocard et al., 2007) claims that inquiry-based methods are effective in terms of increase of student interest and attainment levels. Research shows that learning strategies that activate students in their learning process increase their conceptual understanding of the topic (Minner, Levy, & Century, 2009). Flick and Lederman (2006) claim that students learn best if they work in similar ways as real scientists. Wilson, Taylor, Kowalski, and Carlson (2010) found that teaching based on IBSE resulted in a significantly higher achievement, both in knowledge, scientific reasoning and argumentation. It has also been shown that IBL-tasks stimulate students' creativity and curiosity and ability to work independently in the natural sciences (Llewellyn, 2007). Similar findings have been obtained in mathematics education. Boaler (1997) compared the experiences of students in traditional 'textbook' classrooms with students in investigative/process-based classrooms, and found that students learned more effectively with the investigative approaches. They developed self-motivation and self-discipline as a result of these approaches.

Teachers working with curriculum materials

Teachers use curriculum materials every day in their classrooms, and there is a growing body of scholarship and research that raises questions about the effects of curriculum materials on classroom instruction and pupil learning. What happens when teachers use particular curriculum resources (e.g. IBL, reform programmes), and why? An underlying assumption is that teachers are central players in the process of transforming curriculum ideals, captured in the form of mathematic and science tasks, lesson plans and pedagogical recommendations, into real classroom events. What they do with curriculum resources matters (Lloyd, Remillard, & Herbel-Eisenmann, 2009).

Thus, what teachers do with mathematics curriculum materials, how they 'mediate' them and why, how they choose particular mathematical tasks, and how this complex net of choices influences classroom activity, is crucial for understanding not only the 'implementation' of curricular programmes, but also for informing the work on the development of new programmes, and what students learn in turn.

Seminal work by Ball and Cohen (1999) discusses the role of curriculum materials with respect to teacher learning. They assert that

> [c]urriculum materials could only become central to teacher learning, if the traditional boundaries between texts' presentation of content and teachers' teaching were redrawn to make central the work of enacting curriculum. (p. 7)

In terms of improving instruction, materials are often seen to offer resources for teachers' work with their students, and not designed to encourage teachers' investigations of and work with the material. Sadly, it is claimed, teachers must often learn alone 'with few resources to assist them'.

To ensure a successful implementation of new curricula in school, the teachers' role is essential (Bungum, 2003; Hovdenak, 2009). They are the active agents in the perceived and operational level of curriculum (Bungum, 2003). Klette and Lie (2006) contend that there is much «under-use of learning situations» in Norwegian mathematics and science classrooms, and they registered a narrow repertoire of learning strategies across subjects and classrooms. According to Maaß and Dorier (2010) traditional transmissive teaching still seems to dominate in most European countries, and the small percentage of teachers who are using IBL methods successfully lies between 0 % and 25 % in best cases. Lipowski and Seidel (2009) found that one of the problems with teacher professional development in Norway is the lack of relevance and quality of the courses. The TALIS report (Vibe, Aamodt, & Carlsten, 2009) also highlights 'professional development of teachers' as a main area of concern. The Norwegian authorities claim in the report 'Science for the Future' (Kunnskapsdepartementet, 2010b, p. 32) that

> because so many teachers lack the necessary competence in science subjects, it will be necessary [to have] … a systematic enhancement of competence through continuing and further education and training for teachers.

Mathematics and science tasks as a vehicle for the implementation of IBL

Henningsen and Stein argue that

> the nature of tasks can potentially influence and structure the way students think and can serve to limit or to broaden their views of their subject matter with which they are engaged. (1997, p. 525)

Hiebert et al. similarly argue that students

> form their perceptions of what a subject is all about from the kinds of tasks they do. … Students' perceptions of the subject are built from the kind of work they do, not from the exhortations of the teacher. … The tasks are critical. (1997, pp. 17–18)

This premises that tasks influence to a large extent how students think about mathematics and science, and come to understand their meaning. It has been shown that teachers use textbooks heavily for their selection of tasks (Pepin & Haggarty, 2001). Textbooks both in mathematics and science education are generally not compatible with IBL, and in science education few experiments can be regarded as open. This applies both in Norwegian textbooks and Europe in general (Maaß & Dorier, 2010). According to Pepin (2011) a task analysis tool can help teachers to develop understandings of task characteristics and potential of particular tasks for teaching.

To build students' understanding, a good task should, according to Hiebert et al. (1997), encourage reflection and communication, allow students to use tools and leave behind important learning. Hiebert et al. (1997, p. 25) also claim that understanding is «something that results from solving problems, rather than something we can teach directly». On the basis of these statements it seems crucial to work with analysis of tasks in terms of support for teachers' learning, which in turn can lead to increased use of IBL.

Research design

The study reported on in this paper was conducted within the frame of the EU PRIMAS (*Pr*omoting *i*nquiry in *m*athematics *a*nd *s*cience education across Europe) project, which is one of several on-going European projects that deal with IBL in schools. The project brings together fourteen teams of experts in IBL in mathematics and science education from twelve nations, and it runs over four years. The PRIMAS project aims to effect an influence across Europe in terms of teaching and learning mathematics and science by supporting teachers to develop IBL pedagogies so that, in turn, students gain first-hand experience of scientific inquiry. Ultimately, the objective is that a greater number of students will have a more positive disposition towards the further study of these subjects and the desire to be employed in related fields.

Within the PRIMAS project, we embarked on a professional development programme to include opportunities for teachers to deepen their own understanding of selected key concepts of IBL, to improve their knowledge of ways students may learn and understand mathematics and science content with IBL, and to learn about analysing, selecting and enriching mathematics and science activities for use in their classrooms.

The particular event reported on in this paper is the first PRIMAS-meeting, with 24 mathematics and science teachers, representing one primary school, six lower secondary schools and one upper secondary school. During the two-day meeting we worked with teachers on the following activities:

1. Sorting belief statements to clarify the teachers' points of view
2. Working on mathematics and science tasks that can help students to make connections and develop deeper understandings
3. Discussing characteristics of mathematics and science tasks
4. Working on mathematics and science tasks using a task analysis tool

5. Discussing what we mean by IBL
6. Performing a role play with teachers as actors for and against IBL

After the two-day event teachers were asked to reflect on their experience of the two-day session, and in terms of the following four open questions:

1. Reflect on the experience of the 2-day sessions, e.g. on 'making connections', IBL and the task analysis tool you have used and further developed. Which important insights did you have (if any)?
2. In which ways did the sessions (including the analysis tool) help you to reflect on mathematical & science tasks, and perhaps your pedagogic practice when working with these tasks?
3. When using the analysis tool on mathematics & science tasks, what issues arise for you about the choice of tasks and texts for/in teaching?
4. In which ways might you modify your current teaching resources, and in turn your teaching, in the light of these sessions?

For the analyses of the answers a procedure involving the analysis of themes similar to that described by Woods (1996) was adopted and using the 'constant comparative approach'. Moreover, we tried at one level to maintain the coherence of each teacher's responses over the different questions (using our observations over the two days); at another level we analysed across the twenty-four teachers, and using our understanding of the literature concerning IBL and teachers working with curriculum materials, building explanations and theorisations anchored in the data. In theoretical terms the analyses focussed on the development of a deeper understanding of how teachers experienced the event, what they learnt using the task analysis and the reflective activities associated with it.

Results and discussion

From our analysis of the questionnaire, we identified three main themes (1–3 below) which reflect teachers' experiences of the two-day session based on IBL and task analyses. We will now describe these findings and highlight particular examples that illustrate the points made.

1. Teachers' awareness of task characteristics

During the sessions we wanted to work with the teachers on task characteristics, and restructuring of tasks, to make them more comfortable with modification of textbook tasks, and to show them ways of enriching tasks and how to make the tasks more inquiry-based. Our study indicates that teachers developed higher awareness of characteristics of tasks through these sessions, and thus better awareness of the different features of different tasks. Half of the teachers (50 %) mentioned that they were keen to use more open or problem-based tasks. Being more aware of task characteristics is a good starting point for implementation of IBL-processes. Bungum (2003, p. 292) also concludes that «teachers' aims are an important component of their professional frames and thus highly influential on how curricular ideas are put into practice in schools». The following statements are examples of teachers' raised awareness:

> I was inspired to create / use more tasks that can get students to think/speculate/ wonder/chat/discuss. I see that it might be a good idea to ask more open questions. (Teacher 4)

> I'm going to try to find more open tasks. (Teacher 8)

> [I will use]…more open tasks with the possibility of creative problem solving at several levels for students. (Teacher 10)

2. Teachers' criticality with respect to mathematics and science tasks

Typically, many teachers said that they became more critical with respect to tasks:

> I'm going to be more critical of the tasks I choose. I will be more aware of the tasks' meaning. I will in more cases allow students to work «with their own thoughts». (Teacher 1)

> I have been more critical of the tasks I choose to the students. (Teacher 9)

> [I will]..think more of the tasks I choose. (Teacher 16)

By increasing teachers' criticality, we may stimulate them to use a larger repertoire of tasks and strategies, which is helpful since Klette and Lie (2006) registered a narrow repertoire of learning strategies across subjects and classrooms. An increased criticality with respect to tasks is likely to lead teachers to choose 'richer' tasks that develop students' understanding. If teachers open up selected tasks, to encourage reflection and communication, they are likely to modify their teaching in a more IBL-oriented direction.

Several teachers (21 %) mentioned the aspect of time as a challenge, although we didn't mention framework factors in our questions. A recurring element in teachers' perception is that IBL activities require considerable time, and teachers think they do not have enough time to cover the curriculum by working with such tasks (Maaß & Dorier, 2010). Thus, we contend that it may be advisable to work more frequently with relatively short tasks in our Professional Development courses, to change this attitude. Implementation of IBL may take place in small steps, and thus the first small modifications are crucially important. Through success on small elements teachers are likely to dare to undertake larger steps.

3. Teachers' awareness of the choice of tasks

Several teachers (46 %) pointed out that they became more aware of their choice of tasks through the professional development session and that they developed a more 'systematic' way of choosing tasks:

> [I will]…be more aware of the choice of tasks and the opportunities the various tasks give for learning. (Teacher 12)

> I am usually very much aware of what I want the pupils to learn from a task or for what purpose a task is given. But the sessions have helped me to put my thoughts in a much more systematic manner. It is also a great help to have a thorough analysis tool as we got today. (Teacher 17)

> I have become more aware of the advantages and disadvantages of different tasks and can therefore use the task that is best based on what students should learn. (Teacher 18)

This increasing awareness is positive and encouraging, and we hope this awareness will get teachers to use more varied tasks, since the literature points out the need for a higher repertoire of learning strategies (Klette & Lie, 2006). Some teachers (e.g. Teacher 17) pointed out the usefulness of the analysis tool (based on Pepin, 2011) further developed during the session. This is in accordance with Pepin (2011, p. 19), who found that a task analysis schedule worked as a catalyst for teacher learning, and helped them to develop deeper understandings:

> [T]eachers appeared to need the necessary tools (e.g. task analysis tool, knowledge of how to enrich a task) to stimulate their thinking, and in turn (re-)shape the mathematical tasks for their teaching.

Some of the teachers indicated that they would want to spend more time with «colleague guidance», that is working collaboratively with colleagues in school. One teacher (Teacher 13) pointed out that this collaboration would now be seen as «a resource, not as a threat». In a forthcoming paper (Sikko, Pepin, & Lyngved, submitted) it is reported that 92 % agreed with the statement «I would like to cooperate more closely with other colleagues using IBL». Together these results indicate that discussions among teachers on the levels of subject content and pedagogical practice may be scarce. This assumption is in accordance with findings in the TALIS study (OECD, 2009) which evaluated classroom practices. Their statistical analysis shows that teaching practices – like beliefs about instruction – represent personal strategies and habits to a large extent, and that these vary noticeably among teachers within a school. One of the aims of the PRIMAS project is to establish good communities of practice, and our results indicate that teachers may feel that such communities represent a fruitful way of working – and a good starting point for implementation of IBL.

Conclusions

Based on the findings from this small-scale study it can be argued that working with teachers on curriculum materials can support teacher learning and professional development (e.g. Ball & Cohen, 1999). By working with curriculum materials, and in an encouraging environment, teachers developed a better understanding of the different features of mathematics and science tasks, their affordances and constraints, and they become more critical towards 'less rich' tasks. However, it is less clear whether their development is supported by very different materials (i.e. large open ended tasks) which do not 'fit' their classroom contexts (e.g. in terms of timing). Borko & Putnam (1996) claim that linking to teachers' classroom context is one of the crucial elements of effective professional development. We argue that 'common tasks' (e.g. tasks that teachers can fit into their practices) are likely to be beneficial, and those that lean themselves towards the desired development (e.g. IBL strategies). Moreover, we contend that IBL tasks which foreground particular kinds of processes are helpful for teacher learning.

Mathematics and science tasks highly influence the way students think about, understand and engage in the subjects. Working with teachers on characteristics of mathematics and science tasks is thus a starting point for higher degree of implementation of IBL in Norwegian classrooms. This study shows that our group of teachers developed awareness of choice of tasks and characteristics of tasks through the professional development sessions. Together with increased criticality, this has clear implications for their teacher (and school) resources. In fact 50 % of our teachers answered that they would use more open/IBL tasks in their classes. They also highlighted the importance of variation, and more freedom for students in terms of their own thinking, speculations and discussions. Their criticality of tasks made them more aware of the tasks' aims and purposes, and how different tasks can be adapted to different students. It appeared that all our teachers were open and positive towards problem-solving tasks and teaching, and they wanted support to be able to teach in these ways.

An interesting, though not entirely surprising, result was that teacher learning was enhanced by collaboration. Collaboration with colleagues can influence the need to explain their beliefs and practices and to articulate rationales for instructional decisions, helping teachers to make their beliefs and understandings visible. Most teachers wanted to cooperate more closely with colleagues about IBL, which is one of the main objectives of the PRIMAS project.

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