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ORIGINAL ARTICLE

Implementation of inquiry-based learning in day-to-day teaching: a synthesis

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Abstract This synthesis is designed to provide insight into the most important issues involved in a large-scale implementation of inquiry-based learning (IBL). We will first turn to IBL itself by reflecting on (1) the definition of IBL and (2) examining the current state of the art of its implementation. Afterwards, we will move on to the implementation of IBL and look at its dissemination through resources, professional development, and the involvement of the context. Based on these theoretical reflections, we will develop a conceptual framework for the analysis of dissemination activities before briefly analyzing four exemplary projects. The aim of our analysis is to reflect on the various implementation strategies and raise awareness of the different ways of using and combining them. This synthesis will end with considerations about the framework and conclusions regarding needed future actions.

Keywords Inquiry-based learning · Implementation of inquiry-based learning · Implementation strategies · Dissemination · Design research · Professional development · Resources

1 Introduction

Inquiry-based learning is a more student-centered way of learning and teaching, in which students learn to inquire and are introduced to mathematical and scientific ways of inquiry. In such a setting, primary and secondary school teachers are facilitators of student learning processes. Inquiry-based learning is connected to an enlarged set of goals beyond learning mathematical and scientific content, including students learning how scientists work and equipping students with strategies for further learning (see below).

For decades, mathematics educators have been discussing more student-centered ways of teaching, such as inquiry-based learning or discovery learning, problem-based learning, and mathematical modeling. They have developed theoretical constructs and materials supporting these approaches and carried out related research. Yet, the effects on day-to-day teaching remain limited (Burkhardt and Schoenfeld 2003; van den Akker et al. 2006). One reason for this situation may be that too little attention has been paid to the *dissemination and implementation process* of student-centered ways of teaching (Burkhardt and Schoenfeld 2003).

Implementation is what happens when a planned intervention, an innovation, is set in motion. When an intervention is designed, its designers often do not aim merely for a small-scale implementation, but also wish to disseminate their ideas, materials, etc. Dissemination is mainly a one-way process which offers information. Typical means for dissemination are, for example, conferences, presentations, and journal publications (McKenney and Reeves 2012). New research results of mathematics education can lead to the development of interventions or innovations and these can then be disseminated and implemented.

This process sounds quite straightforward; however, the contrary is true: "An elusive and persistent gulf exists between research in mathematics education and the

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practices of mathematics classrooms, in many countries in the world" (Boaler 2008). This *theory–practice gap* has been repeatedly discussed in papers (see, for example, Burkhardt and Schoenfeld 2003; Begg et al. 2003; Boaler 2008), yet it still does not seem to be the main focus of mathematics educational research. There are several reasons for this theory–practice divide, including:

- A linear Research–Development–Dissemination model with different groups of experts taking responsibility for these three stages with limited communication between them (Begg et al. 2003)
- Research with a lack of relevance for practice, meaning it is too narrowly focused and partially disregards the complexity of mathematics education in specific contexts (Begg et al. 2003; Boaler 2008)
- A lack of—or false—communication outside the research community (Begg et al. 2003)
- A lack of value for the kind of research needed for ensuring effective dissemination of results and sustainable impact on practice (Begg et al. 2003; Burkhardt and Schoenfeld 2003). (Research needs to capture the complexity of the realm of school, therefore a rigorous pre–post–control design can often not be implemented.)

This gap between research and practice is the reason why educational research has been criticized for a long time (van den Akker et al. 2006). Gradually, however, the question of the practice-transfer is attracting more and more attention and there are initiatives addressing the theory–practice transfer. Boaler (2008), for example, describes seven international research studies which have successfully influenced practice. Also, following on from the Rocard Report (Rocard et al. 2007), the European Commission has funded several dissemination projects aiming at a widespread implementation of inquiry-based learning (some of which we will discuss below).

For these reasons, this synthesis—and the present *ZDM* issue as a whole—aims at elucidating the field of implementation strategies for inquiry-based learning. In this synthesis, we will reflect on the implementation of inquiry-based learning by adopting the perspective of design research for the following reasons:

(a) One of the fields of research addressing the need of the transfer into practice is *design research* (see, for example, McKenney and Reeves 2012): "Design research should continue to explore models for diffusion of innovations […]. Equally, it should explore models for scaling successful innovations […]" (Kelly 2006). Within design research, the dissemination and implementation strategies have recently not only been considered to be an inherent part of any design of materials, but also the actual subject of design. This is evidenced by the fact that in its annual conference held in 2012, the International Society of Design and Development in Education (ISDDE) had a first working group on the design of implementation and dissemination strategies (see https://sites.google.com/site/conferenceisdde/working-groups, accessed on 24 July 2013) and the fact that books on design research include reflections on implementation and dissemination strategies (see McKenney and Reeves 2012). Paul Cobb and his colleagues (Cobb et al. 2009) also adopt the perspective of design research in their interventionist study on supporting transformative educational changes.

(b) The design of large-scale dissemination strategies can follow the features of design research. For example, Maaß and Doorman (2013) show how a comprehensive model of implementation and dissemination strategies can be *interventionist*, *utility-oriented*, *theory-based*, and *oriented*, and tested in *iterative*, *process-oriented* cycles (van den Akker et al. 2006; Kelly 2006).

(c) Looking at dissemination and implementation from the perspective of design research actually may help to overcome the theory–practice gap, as design research asks for utility and context-oriented interventions based in theory and including iterative evaluation contributing to theory building (van den Akker et al. 2006; Kelly 2006). The evaluation methods used in design research try to capture the complexity of realm (Kelly 2006).

The focus of this synthesis is on the design of implementation strategies. Based on theoretical reflections, we will develop a conceptual framework for the analysis and design of dissemination and implementation strategies which includes the aspects of resources, professional development, and the involvement of the context. With the help of this framework, we will analyze four exemplary projects and then discuss the usefulness of the framework for understanding and improving dissemination and implementation strategies.

However, we cannot reflect on implementation strategies as such. Any implementation activity needs to build on what is intended to be implemented and its specific demands. Thus, we will first briefly turn to inquiry-based learning itself and the current state-of-the-art of its implementation.

2 Inquiry-based learning

2.1 Definition

The term "inquiry-based learning" generally refers to student-centered ways of teaching in which students raise questions, explore situations, and develop their own ways towards solutions. This approach to teaching is discussed not only in mathematics education (Artigue and Blomhøj 2013), but also—if not more—in science education

(Minner et al. 2010). A definition of inquiry often quoted in science education is that presented by the National Research Council (NRC) (1996, p. 23):

Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations and scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work.

This definition is often used jointly with the five features characterizing inquiry-based learning as expressed by the National Research Council (2000, p.27):

- students create their own scientifically oriented questions;
- students give priority to evidence in responding to questions;
- students formulate explanations based on evidence;
- students connect explanations to scientific knowledge;
- students communicate and justify explanations.

The existence of such definitions does not exclude the co-existence of different interpretations of inquiry-based learning, as these not only result from differences between scientific disciplines. Important differences regard, for instance: the vision of the degree of autonomy to be given to the students in the selection of questions and problems and in the inquiry process itself; the respective weight to be given to the development of inquiry competences and to the development of scientific ideas and techniques aimed at by the curriculum; and the importance attached to real-life questions and phenomena as sources of inquiry (Artigue and Blomhøj 2013).

In addition, different terms and concepts are used for these approaches, including inquiry-based learning, pedagogy or education, discovery-based learning, constructivist learning, and problem solving or problem-based learning. All these are sometimes even said to be synonymous.

Alfieri et al. (2011), for instance, give the following description of "discovery-based learning" in general education: "Allowing learners to interact with materials, manipulate variables, explore phenomena, and attempt to apply principles affords them with opportunities to notice patterns, discover underlying causalities, and learn in ways that are seemingly more robust. Such self-guided learning approaches, like Piaget (1980) proposed, posit the child/learner at the center of the learning process as he/she attempts to make sense of the world" (Alfieri et al. 2011). Moreover, they suggest—following a review of literature—that discovery learning occurs whenever the learner is not provided with the target information or conceptual understanding and must find it independently and with only the provided materials. Despite obvious differences with the NRC definition quoted above, the two of them share evident educational values.

The idea of inquiry-based learning is not new. Educational discourses for the current development of inquiry-based learning can be found in history and traced (Winter 1989; Artigue and Blomhøj 2013):

- in the writings of the famous educationalist Comenius (1592–1670), who complained about the fact that many people left school without permanent education and identified the irrelevant content of school education and learning by reading and repetition as reasons for this;
- later on in the educational philosophy of Rousseau (1712–1778) and his followers such as Pestalozzi (1746–1827); and of course of Dewey (1859–1952), for whom inquiry was the basis of learning, which is why he is often considered to be the founder of inquiry-based education;
- in the strong and original Hungarian tradition of mathematics as exemplified by the writings of the mathematician Polya. He highlighted problem solving as being the most important activity in mathematics education at school and, indeed, considered enhancing student competence in thinking to be the most important objective of school education;
- in the work of psychologists such as Piaget, Vygotsky, Ausubel, and also Bruner. Bruner developed a theory of discovery learning (1970) based on the assumption that a young person cannot learn everything they may need later in life, but needs strategies for further, life-long learning;
- and in the work of Winter (1989), who made "discovery learning" famous in Germany and highlighted the changed role of the teacher in such lessons.

Summing up, although different concepts are used and different aspects of inquiry or discovery are highlighted, the list above shows that student-centered work with cognitive activation and autonomous thinking has been discussed for a considerable amount of time.

In consideration of this situation, we adopt in this journal issue a comprehensive approach on *inquiry-based learning*. Here, IBL refers to a more student-centered perspective of learning mathematics and science that promotes a learning culture in which students are invited to work in ways similar to how mathematicians and scientists work. This means they have to observe phenomena, ask questions, and look for mathematical and scientific ways of how to answer these questions (carry out experiments, systematically control variables, draw diagrams, calculate, look for patterns and relationships, and make and prove conjectures). Students then go on to interpret and evaluate their solutions and effectively communicate their results through various means (discussions, posters, presentations, etc.). This also means that they should try to generalize the results obtained and the methods used, and connect them in order to progressively develop mathematical concepts and structures.

Inquiry-based teaching refers to teaching practice which allows students to do inquiry and thus refers to the teachers' side of inquiry-based learning (Swan 2006). The role of the teacher in such a setting differs from traditional teaching approaches and asks for pedagogies that foster students' construction of their knowledge through inquiry, exploring, and finding their own path to solution. Further, it also supports collaborative work, during which students work together on "interconnected", "challenging" tasks. Here, the teacher's role includes: orienting students towards questions and problems of interest for them that contain interesting learning potential; making constructive use of students' prior knowledge; supporting and guiding when necessary their autonomous work; managing small group and whole class discussions; encouraging the discussion of alternative viewpoints; and helping students to make connections between their ideas and relate these to important mathematical and scientific concepts and methods. In this setting, students are not left alone in their discovery but are guided by the teacher who supports them in learning to work independently.

Inquiry-based learning does not necessarily refer to working on big projects for a longer time; it is also the small steps that are important: an additional question which asks students to give reasons to a calculation, another task which allows students to follow their path of solution, etc.

Inquiry-based learning is connected to an *enlarged set of goals for mathematics education*, such as enhancing student competences in mathematical thinking, building students' motivation to learn, equipping students with strategies for further learning in their future, and assisting students in gaining competences they need in order to work as scientists—and do inquiry (Winter 1989; Artigue and Blomhøj 2013).

The question of to what extent these objectives can really be reached and how far student mathematical content knowledge is effected by inquiry-based learning needs to be answered by research. Although research on the benefits of IBL gives an inconsistent picture of the effects, some meta-analyses support a more positive vision of inquiry-based learning (Minner et al. 2010; Alfieri et al. 2011). For details, see Bruder and Prescott (2013).

2.2 The current state of implementation in day-to-day teaching

To find out more about the current state-of-the-art of the implementation, the question arises of how the quality of teaching can be measured. Classroom research depends on combining different methods of data collection (such as teacher and student reports, and classroom observations), all of which have different advantages and disadvantages (Baumert et al. 2004). For example, an external observer might give more objective insights into what goes on in a lesson than the teacher. However, classroom observation cannot be carried out on a large scale. Thus, insights into day-to-day teaching are either small-scale or need to rely on reports of teachers and students (and perhaps additional, small-scale observations).

Some insights can be gathered from large studies by the Organization for Economic Cooperation and Development (OECD). Teaching and Learning International Survey (TALIS, OECD 2009) shows that transmissive practices predominate in everyday classes in most countries. For example, so-called structuring teaching practices are pointed out as dominant; these include professional routines such as stating explicitly the teaching goals, summarizing previous lessons, reviewing homework, checking exercise books, and checking students' understanding by questioning. As opposed to this, TALIS showed that more student-oriented practices (including students working in small groups to solve a problem, or student self-evaluation) as well as enhanced practices (such as project-oriented work, making a product, or students participating in a debate) are less used.

Within the PISA 2003 study, a national supplementary study on teaching was carried out in Germany. In it, 317 teachers and 3432 students completed questionnaires aimed at elucidating day-to-day teaching styles. Overall, many of the results seemed to indicate that, in 2003, traditional teacher-centered instruction methods still played a major role in German classrooms. According to the study, teachers named the most important aim of mathematics as the mastering of routines and algorithms. Asked about how students learn, teachers emphasized that students should learn autonomously, but conversely seemed quite skeptical about what students actually learn autonomously (Baumert et al. 2004). When asked about their way of teaching, the answers showed that a cognitive-activating teaching style that also offered personal attention could be reconstructed only with a small number of teachers. In a similar way, teaching styles were reconstructed with the help of the students' questionnaires, showing again that the cognitive-activating teaching style also offering personal attention could be reconstructed only for a small number of classes.

To further elucidate the situation across European countries in 2011, Engeln et al. (2013) conducted a large-scale (but not representative) study on teacher IBL views and their classroom practices in 12 different European countries. In total, 51 % of the teachers asked across the 12 countries considered their teaching to be teacher- and not student-centered.

Despite there not being a large-scale, representative study across all European countries, we can conclude that there are indications in many classrooms that mathematics teaching remains quite transmission-based and not inquiry-based.

The discussion above forms the basis for our reflections on how to implement inquiry-based learning. We have seen that a teacher who wants to use inquiry-based learning as a useful teaching ingredient needs to be able to change their role from an instructor to a facilitator. This might be one reason why IBL does not seem to be widespread in Europe. Other factors, for example on a systemic level, may also play a role (Dorier and Garcia 2013). Altogether, it becomes clear that the strategies for the implementation of inquiry-based learning need to be selected carefully.

3 Implementation of inquiry-based learning

The aim of this section is to set up a conceptual framework to analyze and design large-scale dissemination projects for the implementation of inquiry-based learning. Therefore, we will discuss the theoretical background on implementation strategies and then present a conceptual framework based on these considerations illustrated with the help of four exemplary projects.

3.1 Implementation strategies

3.1.1 General approaches to implementation and dissemination

Basically, one can distinguish between a top–down and a bottom–up approach. Within the *top–down* approach, it is assumed that innovation in an organization can be planned and implemented top–down. The so-called "fidelity-perspective" assumes a linear transfer process from the intended innovation to the implementation (Gräsel and Parchmann 2004). In general, top–down planned changes are considered ineffective (Tirosh and Graeber 2003; Ponte et al. 1994); for example, professional development courses imposed on teachers are unlikely to succeed (Bishop and Denleg 2006). School policy often still uses the top–down approach, for example when a new curriculum becomes effective (Schaumburg et al. 2009). In this way, inquiry-based learning has been integrated in mathematics and science curricula in many European countries over the last decade (Dorier and Garcia 2013), but apparently (see Sect. 2.2) not implemented as expected. A reason for this might be that these efforts do not always draw on the current teaching practice and neglect supporting measures such as professional development courses (Schaumburg et al. 2009).

As opposed to the top–down approach, changes in day-to-day teaching can be made from the *bottom up* when groups of teachers work together, identify their needs, develop their own questions, and work on them together (Joubert and Sutherland 2009). In school-based development, teachers and school leaders can benefit from joint, periodic meetings. This approach takes into account all those involved and their beliefs, needs, and teaching practices. However, it neglects organizational aspects of change processes (Schaumburg et al. 2009) and the planned expansion on a large scale. Conducted in isolation, school-based development is in danger of becoming introspective, replicating weaknesses that already exist (OECD 1998).

There are a variety of combinations that exist between these two endpoints. For example, the so-called symbiotic implementation strategy combines the above-mentioned perspectives on implementation. Here, different stakeholders (teachers, scientists, representatives from school administration, etc.) cooperate and bring together different perspectives (Gräsel and Parchmann 2004).

In the following we will look at more concrete implementation and dissemination strategies. All of these can be used either in a more top–down or bottom–up approach.

3.1.2 Providing resources

In this synthesis, we use the term resources instead of materials. Resources are nowadays not considered to be finalized materials distributed to teachers for direct use following a kind of top–down approach. Rather they are "lived resources" (Gueudet et al. 2012). In this regard important questions are: to what extent were potential users involved in the resource development process; and how much does a resource anticipate and prepare for adaptations by the potential user and/or provide alternatives (Gueudet et al. 2013)?

There are resources for teaching, for professional development, or for assessment. They take many forms (videos of lessons and so on) and may have different target groups, such as teachers or teacher educators. They can also be very different in regard to their features in that they promote inquiry-based learning (or not), are user-friendly (or complicated), and/or perhaps include digital resources. Resource content, of course, can vary greatly (Maaß et al. 2013; Gueudet et al. 2013).

In practice, most teachers use resources as guidelines (Gunnarsdottir and Palsdottir 2010; McDuffie and Mather 2006). A growing body of research shows that teaching and curricular materials affect instructional practice and student learning (Ross et al. 2003; Schoen et al. 2003; Stein et al. 2000). However, these research results also show that teaching and learning is determined not only by instructional materials alone, but also by an interaction of other factors such as the curriculum, teachers' beliefs and personal backgrounds, and their professional development experiences. The qualitative analyses of McDuffie and Mather (2006) provide insight into the interplay of teacher use of curriculum materials, their beliefs about mathematics and learning, and the "enacted curriculum". Teacher beliefs influenced the selection and implementation of problem-based mathematical tasks. Mischo and Maaß (2013) showed, in a study on mathematical modeling in which teachers were provided with tasks and detailed lesson plans, that the materials can have an effect on student competences in modeling if teacher beliefs on mathematics education fit to the way of teaching enhanced by the teaching materials.

To sum up, resources can be considered as an important component of dissemination, but which, when used without other strategies for dissemination, are only of limited impact. In conclusion, resources can also be regarded as a prerequisite for dissemination, as teachers need at minimum exemplary materials when implementing new concepts. Thinking of inquiry-based learning as a different perspective on learning, there is a need for an extensive amount for resources across subjects and age groups.

3.1.3 Professional development

Widespread and profound educational change cannot happen without intense support for teachers. This includes both pre-service and in-service education (Ponte 2008). In the following, we will look at criteria for successful professional development before turning to strategies for scaling-up. Due to the nature of the projects discussed later in this journal issue, we will focus on in-service training, though most aspects discussed also hold for pre-service education.

In a meta-analysis, Lipowsky and Rzejak (2012) identify several features of successful professional development activities based on four different aspects.

In regard to *teachers' opinions*, professional development initiatives are considered to be effective if they have clear *relevance for day-to-day teaching*. In addition, teachers appreciate the *exchange of experiences with colleagues.*

Turning to *professional knowledge and competences*, research shows that during reflection, teachers should be requested to *deal with their own beliefs* about the nature of mathematics, and mathematics teaching and learning. This seems to be an extremely important factor when it comes to inquiry-based learning, as teachers often seem to view mathematics education in light of a more transmission-based way of learning (Maaß 2009).

When it comes to *teaching*, professional development interventions have proven to be effective if: the interventions are *long-term* and intensive; *combine learning-off-job in courses with learning-on-job* in school; and give teachers feedback about their teaching. Considering the new role the teacher has to take when organizing inquiry-based learning, this seems especially important.

Speaking to *effects on students' performance*, the Lipowsky and Rzekaj (2012) meta-analysis shows that professional development courses seem to be effective if they have a *clear focus on a certain aspect of teaching*.

All in all, we need to reflect carefully on how teachers learn. "Yet whilst researchers pay careful attention to the agency that mathematics learners have in the learning process and the inadequacy of teaching approaches that embody a teaching by telling mode of instruction, we have paid less attention to the role that teachers need to play when they learn from research" (Boaler 2008). One way of taking care of this aspect is having teachers experience the methods/concepts they are intended to use in school (Putnam and Borko 2000). Another possibility which seems to work successfully in other projects is to encourage teachers to carry out their own little research projects (e.g., with action research, see Müller et al. 2011; Krainer and Zehetmeier 2013).

Another way of supporting teachers' professional development is the so-called "learning-by-job" (Müller 2003). Groups of teachers jointly develop their own professional development with possible approaches here including peer review, mentoring, coaching, study groups, and "self-study" (Joubert and Sutherland 2009). Learning-by-job is also core to the Japanese approach of professional development: the lesson study. In it, a teacher group works together to reflect on the long-term goals of student learning, conduct and observe a "research lesson," observe the learning of the students, and reflect on and optimize the lesson (Takahashi and Yoshida 2004).

When aiming at a large-scale implementation of inquiry-based learning, not only the quality of the professional development is important. The question of how to reach a large number of teachers also has to be addressed thoroughly. However, up to now, small-scale, qualitative research about professional development predominates, with most teacher education research conducted by teacher educators studying the teachers with whom they are working (Adler and Jaworksi 2009). Thus, a major issue when talking about professional development is the question of scaling-up. "… we have done much less studying of what it means to scale-up a program or extend a program that has worked in one setting to another setting" (Adler and Jaworksi 2009).

The issue of how to scale-up professional development courses is complex and closely related to the question of how programs for professional development can be implemented practically within different contextual settings (Adler and Jaworksi 2009). The complexity increases when an implementation is designed for use not only at local but also at international level. In all cases, an important factor for successful professional development programs is their flexibility on the school level, meaning that the program should be adaptable and include as a basis possibilities that take into account and incorporate teacher needs in a given context (e.g., Krainer 1998). Further, the question of scaling-up is closely related to personnel costs and to the complexity of the system: "Scaling-up a classroom-based intervention is not like gearing up factory machinery to produce more or better cars. Scaling-up an intervention in a million classrooms (roughly the number of teachers in the United States) is a different kind of challenge. Not only is the sheer number of classrooms daunting, but the complexity of the systems in which classrooms exist, the separateness of these classrooms, and the private nature of the activity of teaching mean that each teacher has to independently get it and do it right" (Thompson and Wiliam 2008).

In the literature, several strategies for scaling-up are discussed. One of these strategies is the so-called *Cascade Model*. Here, multipliers are trained, who in turn train other teachers. First, this model requires intensive efforts in educating multipliers. Depending on the concept of professional development underlying the cascade model, it can range from being rather top–down to bottom–up in parts. Unfortunately, not much is known about what qualifies someone to be a teacher educator and there is little support for their ongoing learning (Ball and Even 2009; Robert 2009; Krainer 2012). In consequence, one of the major concerns with this model is the question of how much can actually be handed down the cascade (OECD 1998). In relation to inquiry-based learning, this could mean that if a multiplier is, for example, convinced that inquiry-based learning takes so much time that it can be only used at special project days, they might pass this opinion on to their colleagues. "It is not enough to devise a program of professional development that works effectively when it is delivered by its original developers and their hand-picked expert trainers. Where would we find the army of experts needed in the 100,000-plus U.S. schools …?" (Thompson and Wiliam 2008).

Another model for scaling-up is the setting up of so-called *learning communities*. Following, amongst others, Lave and Wenger and their ideas of situated learning, Matos et al. (2009) link teachers' learning to communities of practice at school, who share mutual engagement, joint enterprise, and repertoire. "Assuming learning as a matter of belonging and participating, the community becomes a central element as a group of people who interact, learn together, construct relationships, and develop a sense of mutual engagement and belonging" (Matos et al. 2009). Networks of teachers with similar objectives can support teachers in their efforts (Tirosh and Graeber 2003; Hart 2002), whilst the wish for change may vanish without the support of a network (Wilson and Cooney 2002). In regard to IBL, a supporting factor might be if a teacher has colleagues at the same school or at schools nearby who are also trying to implement inquiry-based learning. Whereas if the teacher has to struggle alone, this might sooner or later prevent their implementation efforts because the teacher has no one with whom to share experiences and challenges. As bottom–up learning is in danger of being introspective, it is important to support these learning communities. Thompson and Wiliam (2008) developed a model in which these learning communities are supported by specific material modules, the respective heads of schools, and by learning community leaders within their schools. These in turn receive specific support from the project in order to carry out their work.

A further model for dissemination is the setting-up of *e-learning communities*. On-line environments offer invaluable opportunities for teachers to reflect and exchange perspectives with peers. Asynchronous communication through e-forums has been found to produce reflective responses and interaction at a deeper level (Linn 2003; Lee et al. 2011) with students often assuming a variety of roles that require more engagement and collegiality with their instructors and peers.

Within all these models of scaling-up, the setting-up of so-called local or regional centers providing advice and advisors can support the different dissemination and implementation strategies. This model is used by several projects, for example Innovations in Mathematics, Science and Technology Teaching (IMST) in Austria (Krainer and Zehetmeier 2013) and the European project Fibonacci (http://fibonacci.uni-bayreuth.de/home.html).

3.1.4 Involving the context

Any innovation to be implemented successfully needs to take into account the implementation context. To this end, an implementation should also be tolerant, as it will inevitably be implemented in different contexts. Thompson and Wiliam (2008) recommend a "tight but loose" framework for teachers' professional development with a tight adherence to central design principles and flexibility in regard to the needs, resources, and constraints occurring in a school context—as long as they do not conflict with the central design principles.

When reflecting on the involvement of the context, two dimensions need to be taken into account: (1) the systemic level of the context; and (2) the extent to which the context is involved.

The context to be taken into account consists of various systems or levels. Figure 1 (Dalton et al. 2007, p. 17, based on the work of Bronfenbrenner) shows the different systemic levels that an individual is connected to (the so-called socio-ecological approach from community psychology).

Within the *microsystem*—as we have seen above—colleagues are an important impact factor. At the *mesosystem*, the level of the *organization* is particularly important. The teacher works in a certain school and, therefore, the extent to which the head of the school supports staff, student, and parent reactions to innovation, and how the school is organized, have relevant impact on the teacher (Joubert and Sutherland 2009; Manouchehri and Goodman 2000). Moreover, the role of parents is crucial as they can either support or hinder the implementation of innovative teaching methods (Mousoulides 2013). On the *locality* level, a local school authority, the professional development courses offered, and the specific university of pre-service education may influence what happens in the classroom.

As regards the *macro-system*, the regulations for pre-service education, in-service education, curricula, and external assessment are particularly relevant (see Joubert and Sutherland 2009).

Looking at these different levels of the context poses the question of to what extent the context is involved. We distinguish three different levels of involvement. A *first step* is to analyze the context into which the intervention is to be implemented (Nastasi et al. 1998). Dorier and Garcia (2013) and Wake and Burkhardt (2013) analyze the context of 12 different countries (regions), in the first case in order to facilitate the implementation of activities aiming at a widespread implementation of IBL, in the second case to give recommendations for policy.

Fig. 1 Socio-ecological system levels (Dalton et al. 2007)

A *second step* would be to disseminate information actively to relevant key actors. For example, if inquiry-based learning is to be implemented on a large scale, a successful dissemination process can create awareness of the need for inquiry-based learning in students, parents, and society as a whole which, in turn, might have an influence on teachers.

A *third step* would be to actively involve key actors. A strategy that actively connects relevant key actors from the micro-system to the macro-system is provided by the *Participatory Intervention Model* (PIM), a model situated in school psychology. The goals of PIM are to integrate theory and research in the development of culture- or context-specific interventions and promote ownership and empowerment among the stakeholders responsible for sustaining and institutionalizing the intervention after the support provided by interventionists or consultants has ceased. For example, in school-based interventions, partners are likely to include teachers, school administrators, parents, students, community leaders, and policy makers. Research shows that PIM has potential to develop effective partnerships with key actors in relation to schools (Nastasi et al. 1998).

3.2 A conceptual framework

A conceptual framework of implementation strategies can (1) help to analyze and compare existing projects in order to learn more about their strengths and (2) support the designer in developing new large-scale implementation models.

An example of such a conceptual framework is presented by Cobb and Jackson (2012). Following on from their analytic learning design perspective, they distinguish between four types of support for implementing innovation: new positions (such as a one person per district/school responsible for organizing the professional development in mathematics education—a mathematics coach); learning events (professional development either intentional or unintentional, on-going or discrete events); new organizational routines (e.g., regular meetings between the principals of schools and the mathematics coaches, such as visits in school); and new tools (such as classroom materials, materials for professional development, revised curriculum frameworks). This framework was designed for the US context and the named aspects are of general value. We take these aspects into account for our analysis; however, based on our theoretical discussion, we will adopt our framework to the specificity of inquiry-based learning and to the context of European projects.

We developed a conceptual framework which summarizes and structures the theoretical reflections. It comprises the sections resources (new tools), professional development (learning events), and involvement of the context. The aspects "new organizational routines" and "new positions" as used by Cobb and Jackson (2012) are considered to be included in "involvement of the context." The framework is shown in Fig. 2.

We do not consider this framework to be comprehensive or the only way to analyze and compare existing dissemination projects. Certainly, relevant categories can be built in different ways and more categories/aspects can be found. We only drew from the theoretical background and from our knowledge of several dissemination projects and tried to set up a list of features which might be useful when looking at some examples. Furthermore, we do not consider that this framework allows for an unambiguous allocation of projects or that it requires discussion of each of its aspects when looking at a project. Rather, this framework provides an overview of aspects which might be considered.

In the following, we will use our conceptual framework to analyze and discuss four exemplary projects. The examples chosen here are neither comprehensive nor representative. In choosing the two big national initiatives and two international projects presented here, we attempted to capture projects that used different dissemination and implementation strategies. Naturally, our choice was also influenced by what we know about other projects. Thus, the sample is only intended to illustrate different strategies.

We will first briefly introduce the four projects and then compare them in regard to resources, professional development, and context involvement. The reports on the projects are based on information gathered from their respective homepages and have been validated by representatives of the projects.

3.2.1 La main à la pâte (Lamap) (http://www.fondation-lamap.org, http://www.lamap.fr)

Lamap was launched in 1996 at the initiative of members of the French Academy of Science. The project's initial

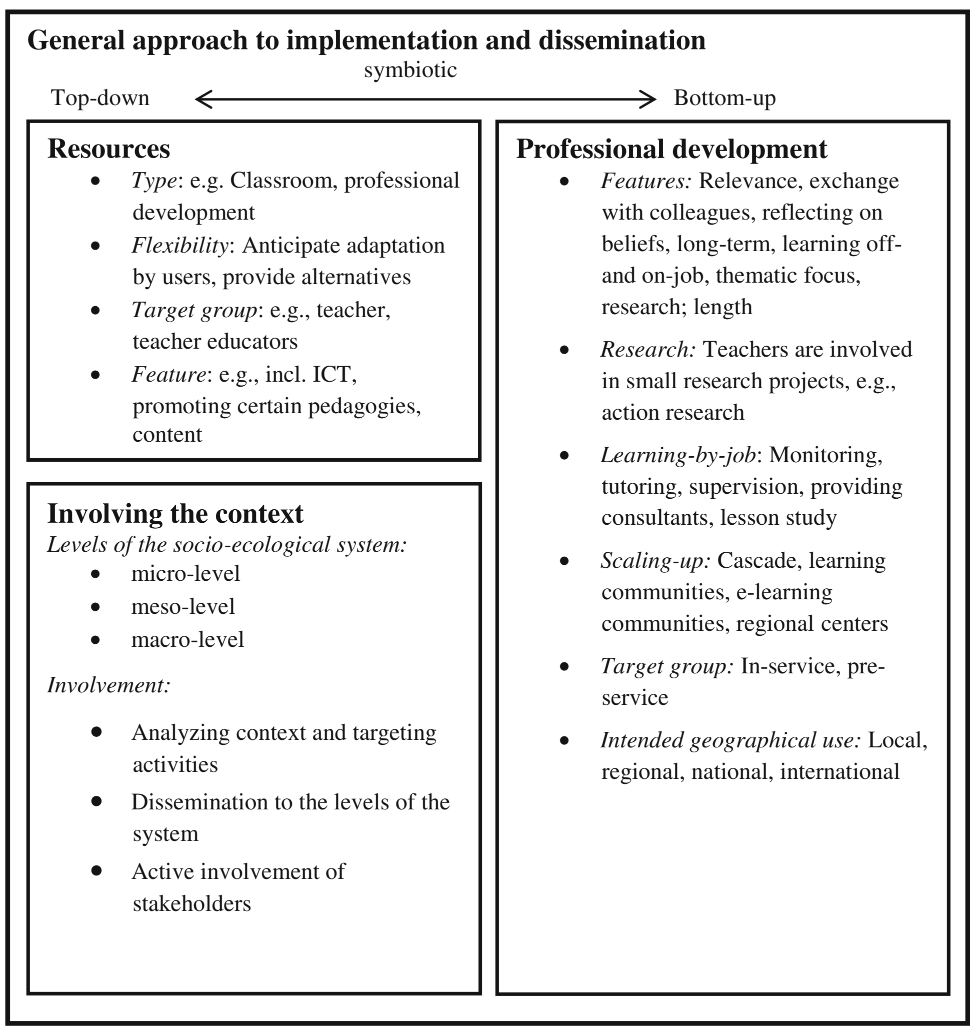

Fig. 2 Framework for analyzing implementation projects

ambition was to revitalize science education in primary schools from the early grades by promoting an inquiry-based pedagogy serving jointly authentic scientific learning, mastery of language, and citizenship education. Since then, it has developed with the support of the French Ministry of Education and of the Institut National de Recherche Pédagogique (INRP) now French Institut Français d'Éducation (IFé), and other partners. Thanks to a network of 20 pilot centers having about 3,000 associated classes and to the three Houses for Science recently created, Lamap activities now cover the whole country. Lamap was able to influence curriculum policy and, for instance, its vision inspired the new science curriculum for primary school. As of 2006, Lamap extended its activities towards junior high school.

The strategy used in Lamap for supporting the large-scale implementation of IBL is quite complex and combines top–down and bottom–up strategies. Main strategy components are production and dissemination of resources and teachers' professional development.

3.2.2 The national Austrian project IMST (http://www.imst.ac.at)

The Austrian project Innovations in Mathematics, Science and Technology Teaching (IMST) was launched in 1998 after the results of the Third International Mathematics and Science Study (TIMSS) 1995 and later driven by the results of PISA. IMST was launched in three steps (for more details, see Krainer and Zehetmeier 2013).

The basic principles of IMST were: (1) a nation-wide effort to implement innovative teaching needs to bring together practice, research, and policy, and needs to stimulate the development of adequate structures; (2) inquiry-based learning cannot be confined to students, but is equally important for teachers, researchers, and representatives of educational administration and policy. The second principle led to a high degree of autonomy in relation to the professional development, the research involved, and the evaluation.

3.2.3 The European project PRIMAS (http://www.primas-project.eu)

Since 2009, the European Union has funded several extensive international projects aimed at a large-scale implementation of inquiry-based learning within a funding period of three to 4 years. These projects require having a major focus on running pre- and in-service professional development courses. One of these projects is Promoting Inquiry in Mathematics and Science Education (PRIMAS across Europe, lifetime 2010–2013), within which 14 universities in 12 countries cooperate. The overall approach of PRIMAS is more top–down, but takes into account end-user needs (Maaß and Doorman 2013).

3.2.4 Fibonacci (http://www.fibonacci-project.eu)

Like PRIMAS, Fibonacci is a Framework 7 (FRP7) European project and started on 1 January 2010 for the duration of 38 months. The aim of the Fibonacci project was to contribute to the dissemination of IBL by designing, implementing, and evaluating a dissemination process based on three pillars: the promotion of IBL; the development of twinning between RC (Reference Centers) and TC (Twin Centers); and the involvement of the local community by creating a Community Board to enhance the sustainability of developed actions. The Fibonacci consortium included 25 members from 21 countries (Academies of Sciences, Universities and Teacher Education Institutions, …). The dissemination process started with 12 RCs having a recognized expertise for sustainable implementation of inquiry-based learning at local or national level and 12 level one TCs (TC1). The number of centers involved was progressively increased to 60 by project end. In this project, the dissemination concept was neither a top–down nor bottom–up process, "but rather a transfer of semi-formalised practices and experiences that have reached a satisfactory level of recognition, expertise and sustainability on a local scale" (Fibonacci, http://fibonacci.uni-bayreuth.de/project/principles/overview.html). In this transfer, specific attention was paid to the specificities of local contexts and to the adaptation of strategies to these specificities.

3.2.5 Resources

Lamap offers a large number of resources classified into classroom resources, resources attached to thematic projects, scientific and pedagogical documents, and training resources (for teachers and teacher educators—but mostly for teachers) contained on a website with several thousand pages. The activity report for 2011 notes that there are 39,000 registered members, and that about 75 % of the consultations concern classroom resources (61 %) and thematic projects (14 %). These resources are produced by the Lamap team and its collaborators (scientists, researchers, expert teachers, and teacher educators) and often include information on actual classroom realizations.

IMST published three books and a CD-ROM, three booklets (on examination culture, school development, and writing), and 39 issues of a nation-wide newsletter (the last three issues focused on "competences and standards in mathematics and science," "reading and writing," and "organized learning"). Teachers' "reflective papers" and reports on networking (written experiences and analyses) are available at https://www.imst.ac.at/texte/index/bereich_id:15/seite_id:16. So far, more than 1,000 IMST papers from teachers to teachers have been produced. The focus of IMST was not on producing new teaching materials, but on illustrating processes of change in teaching.

PRIMAS provides resources for both classroom use and professional development. The resources are for an international use, but are to be adapted to different national contexts. As the main PRIMAS focus is on long-term professional development courses, it has mainly adapted materials which had already proven efficacy.

In *Fibonacci*, the collective development of resources was an important dimension. Some of these were "background documents" and clarified the nature of inquiry-based learning. Others, the so-called "companion resources," dealt with five major topics: Tools for Enhancing Inquiry in Science Education; Implementing Inquiry in Mathematics Education; Setting-up, Developing and Expanding a Center for Science/or Mathematics Education; Integrating Science Inquiry across the Curriculum; and Implementing Inquiry beyond the School. All of these include both general reflection and insightful examples from practice.

These explanations show that a variety of resources (materials) has been produced. Whilst in Lamap and PRIMAS the focus seems to have been on classroom materials, IMST apparently produced more materials on certain pedagogical and subject-related topics, supporting teachers in their endeavor to evolve their teaching. Reflective papers are a very specific feature in IMST. Fibonacci puts a strong focus on the collective development of background and companion materials addressing both theoretical and practical issues, and directed towards a diversity of audience from teachers to local stakeholders.

3.2.6 Professional development

In *Lamap*, the pilot centers mentioned above play a prominent role for implementation of inquiry-based practices and dissemination of good practices, as well as for assessing the impact of inquiry-based learning methods on teachers and pupils. They organize training sessions for in-service teachers, mentoring, classroom observations, and also long-term collaborative work between teachers, teacher educators, and scientists. One important feature is the role played by scientific partners (from universities and engineering schools) collaborating with teacher educators. Lamap has, for instance, developed a network of scientific consultants that teachers can contact with questions through its website. Professional development activities have been offered and/or piloted at the local, regional, and national levels. The 2011 activity report mentions 82 training sessions organized by the Lamap team in four categories: teachers' training, teacher educators' training, training about thematic projects, and scientific training. The Lamap activities addressed in-service teachers.

More recently, four regional "Houses of Science" have been created as prototypes aiming for a renewal of continuous professional development in sciences. In order to reach this goal the network offers teachers' and teacher educators' professional development courses strongly rooted in living and contemporary science, designed and led jointly by educators, scientists, and industry stakeholders.

In the so-called network program, *IMST* supports regional networks and school projects on the basis of a clear definition of aims the network should reach. These networks are to support the exchange of participants' educational experiences and knowledge. Further, in six topic specific programs that address both general pedagogy and subject-related education, teachers can submit innovative teaching and school projects and be supported for 1 year by teams of scientists and school experts. This cooperation is intended to strengthen the links between school practice and research in education. All in all, the IMST approach to professional development is quite bottom–up, though not in danger of being introspective, as schools are supported by local subject coordinators. Due to the fact that schools can submit their own projects, these are relevant for teachers. Being embedded in networks, they support the exchange between teachers. When taking part in these projects, teachers have to write reflective papers based on the idea of action research (Altrichter et al. 2008), which also encourages them to reflect on their beliefs. These projects are long-term and combine learning-on-job with phases of learning-off-job when the school teams are supported by regional or local subject coordinators. Scaling-up is ensured by the number of projects (learning communities) which are supported by subject coordinators from regional centers. In IMST, new positions and new institutions were created.

In *PRIMAS*, each country involved holds professional development courses. These follow the so-called spiral model, allowing teachers to experience and analyze inquiry-based learning themselves, implement it in their classrooms, and reflect on it in the next professional development session. The professional development activities start off from teachers' needs, allow teachers to reflect on their beliefs on mathematics education, and have a clear focus on IBL. The PRIMAS team organizes the courses, so these can thus be considered as top–town. However, teacher wishes have been taken into account, so courses can also be seen as partly bottom–up. In order to scale-up measures, multipliers had been educated before the professional development courses started. As opposed to IMST, teachers do not carry out their own research projects and new positions as consultants could not be created. Learning-by-job for teachers is partly encouraged, but is not an inherent component of the professional development courses. The courses are designed for international use. PRIMAS also carried out courses for pre-service teachers.

Professional development was also a crucial dimension of *Fibonacci*. It included formal training sessions or workshops, coaching from more experienced teachers or from education researchers, scientific support from science and/or engineering students, co-teaching, and conducting individual or collective action research on the teachers' own practice. In line with the attention paid in Fibonacci to local contexts, each center was expected to draw on these different types of activities to build its professional development offer whilst taking into account the local potential and needs. Emphasis was also put on the systematic development of teacher networks. As shown by the data collected by EduConsult, the enterprise responsible for the external evaluation of the project, professional development indeed took a diversity of forms according to the partners and countries involved. Formal professional development could vary for instance from a few days to substantial accredited programs (up to more than 100 h in Slovakia). Consequently, the different dimensions of professional development as listed in the conceptual framework cannot be discussed here in more detail.

We can see from the descriptions that all projects follow different strategies for professional development. Whilst IMST works school-based with schools developing their own projects (bottom–up) and doing research, PRIMAS uses a more top–down approach to provide long-term professional development courses in each country following an international model which is adapted nationally. Lamap and IMST as national projects make strong use of regional networks, whilst in Fibonacci the approaches vary depending on the reference or twin center within the global frame agreed. As opposed to IMST, PRIMAS and Lamap did not involve teachers in research.

3.2.6.1 Involvement of the context The *Lamap* activities involve all the levels of the socio-ecological context. There is no doubt that the strong support of the French Academy of Sciences is helpful for gaining the attention and interest of policy makers, stakeholders, and media. Every year, for instance, the Academy of Sciences awards the Lamap prizes to teachers and students who have developed exemplary work in the Lamap spirit. Lamap puts a high emphasis on dissemination and *public awareness* of IBL through conferences and seminars, expertise, and recommendations. Lamap also encourages active involvement of families and/or the neighborhood in addition to the work done in class. Furthermore, it actively collaborates with policy makers, researchers, and representatives of industry.

Before the implementation of *IMST*, an analysis of the results of TIMSS was carried out and suggestions for strategies based on this analysis were made. Parent representatives had been involved in several advisory board meetings. Recently, IMST presented its experiences to representatives of the various parent associations in Austria. Several activities (some as IMST spin-offs) for students were developed and delivered by Regional Networks and centers. One example is the "Experimentale," which is organized by the Regional Network of Upper Austria every 2 years. More than 90 secondary schools of this federal province are involved in this large science fair, while 12,000 pupils visit to learn about and from science experiments every year.

Since IMST aims at bringing together practice, research, and policy, representatives of these fields are intensively involved in IMST initiatives, including national "cooperation meetings" where representatives from of all these fields meet. In particular, collaborative projects with universities, university colleges of education, and industry are launched.

In *PRIMAS*, an analysis of all systemic levels of the context was carried out in every country in order to target the dissemination and implementation strategies to the needs of end-users (Dorier and Garcia 2013). Based on this, the international model of professional development was then nationally adapted to the individual countries (Maaß and Doorman 2013).

PRIMAS also had a focus on dissemination to a variety of target groups, including teachers (to win them for the professional development courses or to inform them about inquiry-based learning), students, parents, teacher educators, and local policy makers. Dissemination activities included talks at seminars, meetings, conferences, papers in teacher and scientific journals, addressing media, and student days in order to create public awareness on the need and aims of including IBL in mathematics education.

In order to involve stakeholders from the outset of the project, every country set up a so-called national consultancy panel of stakeholders (teacher educators, teachers, parents, and students, policy makers) in order to target all activities to the needs of the end-users and develop new ideas for implementation. As opposed to the national projects IMST and Lamap, PRIMAS only received limited support from national governments and, thus, new rules and new organizational routines were not created within this project.

In *Fibonacci* as well, attention was paid to the diversity of contexts, even if no systematic study of contextual characteristics was part of the project (as was the case in PRIMAS). Regarding the involvement of the different levels of the socio-ecological contexts, this was also a major concern from the start of the Fibonacci project and the specific theme of one of the companion resources. All Fibonacci centers were encouraged to set up a community board gathering local stakeholders. However, the external evaluation points out that not all Fibonacci partners fully achieved their goals in that respect.

All projects included the involvement of the context to some extent. Whilst PRIMAS and IMST carried out an analysis in relation to the context, Fibonacci and Lamap did not. PRIMAS, IMST, and Lamap actively disseminated to all systemic levels of the context. Moreover, all three projects also try to involve stakeholders actively in their work. As regards an involvement of the context, the involvement of high level policy makers seems to be extremely important, as the discussion of IMST and Lamap shows.

Altogether, the discussion above shows that the different projects draw on very different combinations of strategies and, further, that different strategies can work in various contexts.

The examples show that neither the top–down nor the bottom–up approach is used in a pure form. However, one can see that IMST has a more bottom–up organization than, for example, PRIMAS.

All implementation models show flexibility, but the degree of flexibility demonstrated varies. Whilst in PRIMAS there is an overarching international concept which can be adapted nationally, in Fibonacci the focus is on twinning reference centers on a more systemic level, allowing each center to choose strategies they consider to be appropriate. It also becomes clear that long-term, national projects have more extensive possibilities not available to shorter ones, such as PRIMAS and Fibonacci, which, for example, could not establish new positions such as consultants. Furthermore, European projects have to struggle with different cultures, but this also offers the possibility to learn about different educational contexts in various countries.

4 Conclusions

The intention of this synthesis report was to set the scene for a more fundamental, theory-oriented approach to the design of dissemination and implementation strategies.

Our theoretical reflections above show that the implementation of inquiry-based learning is a complex endeavor requiring extensive knowledge about the concept of IBL and different dissemination and implementation strategies. Based on our theoretical reflections on dissemination strategies, we developed a conceptual framework which shows us in which ways resources, professional development, and involvement of the context can be used as means for dissemination aiming at a large-scale IBL implementation.

Our analysis of the four example projects shows how the different projects took into account those aspects, and thus supports the analysis of dissemination and implementation strategies.

When thinking of the design of dissemination and implementation strategies, the conceptual framework highlights important aspects that need to be taken into account when designing the activities. Is that sufficient for the design of dissemination activities? At the beginning of the paper, we reflected on the existing theory–practice divide. We also referred to design research as a possibility for overcoming this divide. Therefore, for a more in-depth reflection on the framework, we will now see how far it helps to follow the features of design research: any design should be interventionist, utility-oriented, context-oriented, and theory-based. It should also be process-oriented by following iterative cycles of evaluation and improvement. In the end, it should contribute to theory building (van den Akker et al. 2006; Kelly 2006).

An activity to disseminate and implement inquiry-based learning is per se *interventionist*. The conceptual framework provides a list of categories to ensure that the activities for dissemination and implementation are actually *utility-orientated* and can be used in the real world, for instance with the help of an analysis of the context, by making the professional development relevant for day-to-day teaching, and so on. An analysis of the context and the active involvement of stakeholders can also help to target the intervention to the context and by this ensure its *context-orientation*.

However, the conceptual framework—by its very nature and despite being theory-based—cannot ensure that the design is not only craft-based (Burkhardt and Schoenfeld 2003) but also explicitly linked to research and follows the processes of design research. A close link between implementation and dissemination activities on the one hand, and research on the other, as envisaged by design research would allow: (1) the projects to draw on already existing knowledge and (2) the researchers to learn more about what strategies are successful under which conditions. This in turn would ensure a high quality of dissemination activities.

However, there still seems to be a separation between research and implementation (Walker 2006). “Our expertise in educational design tends to be segregated from expertise in research. The former is locked up in institutions that have development responsibility and the latter in research institutions” (Edelson 2006).

Thus, in order to link research and implementation more closely, the theoretical basis of respective activities should *first* be made explicit.

Second, a discussion on how dissemination and implementation strategies can be evaluated thoroughly and in a feasible way should be encouraged, to allow for a substantial *process-oriented* evaluation of the dissemination and implementation activities and an *iterative* improvement.

Within design research, a variety of evaluation strategies is discussed, such as screening, expert appraisal, walk-through, micro-evaluation, and try-out (Nieveen 2007). However, these methods are not those which are used in traditional research. Kelly (2006) demands (with reference to other authors): "Design research should pay greater attention to advances in mixed methods […] and more expansive views of randomized field trials." Furthermore, there is little experience with evaluating of design and, in particular, implementation strategies. As Edelson (2006) elaborates: "While I am able to say that good design research requires plans for research-driven design, systematic documentation, formative evaluation, and generalization, I must acknowledge that we lack accepted methods for use in developing and executing these plans. Each design research effort must essentially invent these methods themselves."

Considering large implementation and dissemination projects and their variety of activities necessitates answering the questions: How can the success of the professional development activities be measured? How can implementation and spread be measured?

In order to answer the first question, you would have to evaluate teacher beliefs, observe their lessons, and perhaps measure student outcomes. As we are talking about a large-scale implementation, any evaluation would be extremely expensive in terms of personnel and time resources. When talking about measuring success in an international project, the situation is even more complicated due to the different languages used (Baistow 2000).

When thinking about measuring spread, the situation becomes even more complicated. It is of course possible to count participants of big events. But how will these people spread the innovative teaching methods themselves? What impact would an article (or several) in a newspaper have?

Considering all these aspects, an appropriate evaluation seems to be a real challenge which requires a balance between more rigorous evaluation methods and newer methods such as the above-mentioned screening, walk-through, etc. The approaches for evaluating a dissemination model would need to be reflected thoroughly and communicated with the research community.

Third, these evaluation strategies should not only allow for measuring the success of the intervention, but also provide for contributing to *theory building* about which implementation strategies have what impact under which conditions.

Within the discussion of design research, we learn that the role that design research can play in the larger research endeavor is not hypothesis testing (Edelson 2006) but rather finding out to what extent a design works and developing an understanding of how it does so within a specific context (Gravemeijer and Cobb 2006).

Edelson (2006) suggests the following types of theory building for design research:

A *Context Theory* is a theory about a design setting, such as a description of the needs of a certain population of students, the nature of certain subject matter, or of the organization of an educational institution.

An *Outcomes Theory* describes the effects of interactions among elements of a design setting and possible design elements. An outcomes theory explains why a designer might choose certain elements for a design in one context and other elements in another.

A *design framework* is a generalized design solution. A design framework provides guidelines for achieving a particular set of goals in a particular context. A design framework rests on domain theories regarding contexts and outcomes.

A *design methodology* is a general design procedure that matches descriptions of design goals and settings to an appropriate set of procedures.

Which of these theories could be developed within the evaluation of implementation strategies? As has been said, the idea of considering the design of implementation and dissemination strategies as design research is relatively new. A possibility is to consider an analysis of the context in which the implementation model is to be implemented as context theory, and the resulting plan of the implementation as an outcomes theory. The outcome at the end of the project might be a design framework. However, we still lack experience on how such a theory in relation to dissemination and implementation strategies might appear. Here, more examples are needed to show in which way(s) the design of implementation and dissemination strategies can contribute to theory building. The PRIMAS evaluation might give new insights into how such a project might contribute to theory building (Maaß and Doorman 2013).

As we can see, examining the design of large-scale dissemination activities from the perspective of design research can actually provide a means to overcome the theory–practice divide. However, having highlighted the necessity to connect implementation and research, we must not forget that the aim of dissemination activities is not only capacity building, but also actual implementation. As we have seen in the discussion of the four projects, with the help of the conceptual framework, the support of policy makers is essential for the success of dissemination activities and the activities must be targeted to the need of the end-users. However, the goals of policy makers and the needs of teachers may change during the course of a long-term activity. So any activity in implementation must balance between research standards, policy demands, and teachers' needs. Within a small-scale project with a lot of scientific freedom to define (research) goals, it is easier to cope with theory building than having big, nation-wide projects with many different goals set by different stakeholders. For this reason, we must bear in mind this balance between different goals and stakeholders when designing interventions, trying to bridge the theory–practice gap, and judging the evaluation and analysis methods of these activities. The papers in this issue give a vivid picture of this balance.

4.1 Outlook on the journal issue

After this synthesis report, Artigue and Blomhøj (2013) discuss in more detail the features of inquiry-based learning—in particular regarding other concepts such as problem solving and modeling. Bruder and Prescott (2013) analyze the effects of IBL on students and Engeln, Euler, and Maaß (2013) present the results of a quantitative study which dealt with teacher perspectives on the implementation of inquiry-based learning in their classes.

This issue then turns to the implementation processes with the next three papers focusing on the impact the context can have in any dissemination process. Dorier and Garcia (2013) describe the analysis of various European contexts which helped the European Project PRIMAS to tailor interventions to their target groups. Wake and Burkhardt (2013) present an analysis of context used to analyze policy implications, and Mousoulides (2013) focuses on parent involvement.

We then look at two exemplary projects: Krainer and Zehetmeier's (2013) paper gives more details on the Austrian implementation project IMST, and Maaß and Doorman (2013) present the European project PRIMAS.

As all these papers are written from the perspective of European mathematics educators, it was important to us to provide comments from other viewpoints. For that reason, the American, Asian, and Australian perspectives complement this issue (see Chin and Lin 2013; Schoenfeld and Kilpatrick 2013; Stillman 2013).

Because the complex topic of implementation of inquiry-based learning is neither a topic that is well-researched, nor one that can be easily researched within a rigorous approach, the methodological approach of the papers selected for this issue provides a balance between theoretical contributions, empirical research giving global or local pictures, experienced-based reports on large-scale implementation projects, reports on projects from the perspective of design research, and document analyses giving insight into the rich diversity of national educational contexts. This diversity of dimensions is needed and relevant because it provides a rich and comprehensive picture of important issues regarding the implementation of inquiry-based learning.

References

Adler, J., & Jaworksi, B. (2009). Public writing in the field of mathematics teacher education. In R. Even & D. Loewenberg Ball (Eds.), *The professional education and development of teachers of mathematics—The 15th ICMI study* (pp. 249–254). New York: Springer.

Alfieri, L., Brooks, P., Aldrich, N., & Tenenbaum, H. (2011). Does discovery-based instruction enhance learning? *Journal of Educational Psychology, 103*(1), 1–18.

Altrichter, H., Feldman, A., Posch, P., & Somekh, B. (2008). *Teachers investigate their work. An introduction to action research across the professions* (2nd ed.). London: Routledge.

Artigue, M., & Blomhøj, M. (2013). Conceptualising inquiry-based education in mathematics. *ZDM - The International Journal on Mathematics Education*, *45*(6) (this issue).

Baistow, K. (2000). Cross-national research: what can we learn from inter-country comparisons? *Social Work in Europe, 7*(3), 8–13.

Ball, D. L., & Even, R. (2009). Strengthening practice in and research on the professional education. In R. Even & D. Loewenberg Ball (Eds.), *The professional education and development of teachers of mathematics—The 15th ICMI Study* (pp. 255–260). New York: Springer.

Baumert, J., Kunter, M., Brunner, M., Krauss, S., Blum, W., & Neubrand, M. (2004). Mathematikunterricht aus Sicht der PISA-Schülerinnen und -Schüler und ihrer Lehrkräfte. In Deutsches PISA-Konsortium (Ed.), *PISA 2003 – Der Bildungsstand der Jugendlichen in Deutschland – Ergebnisse des zweiten internationalen Vergleichs* (pp. 314–354). Opladen: Leske + Budrich.

Begg, A., Davis, B., & Bramald, R. (2003). Obstacles to the dissemination of mathematics education research. In A. J. Bishop, M. A. Clements, C. Keitel, J. Kilpatrick, & F. K. S. Leung (Eds.), *Second international handbook of mathematics education* (pp. 593–634). Dordrecht: Kluwer.

Bishop, K., & Denleg, P. (2006). Science learning centres and governmental policy for continuing professional development (CPD) in England. *Journal of In-service Education, 32*(1), 85–102.

Boaler, J. (2008). Bridging the gap between research and practice: international examples of success. In M. Menghini, F. Furinghetti, L. Giarcardi, & F. Arzarella (Eds.), *The first century of the International Commission on Mathematics Instruction (1908–2008): Reflecting and shaping the world of mathematics education*. Roma: Instituto della Enciclopedia Italiana foundata da Giovanni Treccani.

Bruder, R., & Prescott, A. (2013). Research evidence on the benefits of IBL. *ZDM - The International Journal on Mathematics Education*, *45*(6) (this issue).

Burkhardt, H., & Schoenfeld, A. (2003). Improving educational research: towards a more useful influential and better-funded enterprise. *Educational Researcher, 32*(9), 3–14.

Chin, E.-T. & Lin, F.-L. (2013). A survey of the practice of a large scale implementation of inquiry-based Mathematics Teaching - from Taiwan's perspective. *ZDM - The International Journal on Mathematics Education*, *45*(6) (this issue).

Cobb, P., & Jackson, K. (2012). Analyzing educational policies: A learning design perspective. *The Journal of the Learning Sciences, 21*, 487–521.

Cobb, P., Qing, Z., & Dean, C. (2009). Conducting design experiments to support teachers' learning: A reflection from the field. *Journal of the Learning Sciences, 18*(2), 165–199.

Dalton, J. H., Elias, M. J., & Wandersman, A. (2007). *Community psychology: Linking individuals and communities*. Belmont: Thomson-Wadsworth.

Dorier, J. & Garcia, F.J. (2013). Challenges and opportunities for the implementation of inquiry-based learning in day-to-day

teaching. *ZDM - The International Journal on Mathematics Education*, *45*(6) (this issue).
Edelson, D. (2006). What we learn when we engage in design: implications for assessing design research. In J. van den Akker, K. Gravemeijer, S. McKenney, & N. Nieveen (Eds.), *Educational design research* (pp. 100–106). Oxford: Routledge Chapman & Hall.
Engeln, K., Euler, M., & Maaß, K. (2013). Inquiry-based learning in mathematics and science: a comparative baseline study of teachers' beliefs and practices across 12 European countries. *ZDM - The International Journal on Mathematics Education*, *45*(6) (this issue).
Gräsel, C., & Parchmann, I. (2004). Implementationsforschung–oder der steinige Weg, Unterricht zu verändern. *Unterrichtswissenschaft, 32*(3), 196–214.
Gravemeijer, K., & Cobb, P. (2006). Design research from a learners' perspective. In J. van den Akker, K. Gravemeijer, S. McKenney, & N. Nieveen (Eds.), *Educational design research* (pp. 17–51). Oxford: Routledge Chapman & Hall.
Gueudet, G., Pepin, B., & Trouche, L. (Eds.). (2012). *From texts to 'lived' resources*. New York: Springer.
Gueudet, G., Pepin, B., & Trouche, L. (2013). Textbooks' design and digital resources. In C. Margolinas (Ed.), *Task design in mathematics education. Proceedings of ICMI Study 22* (Vol. 1, pp. 327–337). Oxford.
Gunnarsdottir, G. H., & Palsdottir, G. (2010). The implementation of the intended curriculum in teaching materials: authors' perspective. In B. Sriraman, C. Bergsten, S. Goodchild, G. Palsdottir, B. Dahl, & L. Haapasalo (Eds.), *The first sourcebook on Nordic research in mathematics education* (pp. 539–549). Greenwich: IAP Information Age Publishing.
Hart, L. C. (2002). A four-year follow-up study of teachers beliefs after participating in a teacher enhancement project. In G. C. Leder, E. Pehkonen, & G. Törner (Eds.), *Beliefs: A hidden variable in mathematics education?* (pp. 161–176). Dordrecht/Boston/London: Kluwer.
Joubert, M., & Sutherland, R. (2009). *A perspective on the literature: CPC for teachers of mathematics*. London: National Centre for Excellence in the Teaching of Mathematics.
Kelly, A. (2006). Quality criteria for design research: evidence and commitments. In J. van den Akker, K. Gravemeijer, S. McKenney, & N. Nieveen (Eds.), *Educational design research* (pp. 107–118). Oxford: Routledge Chapman & Hall.
Krainer, K. (1998). Some considerations on problems and perspectives of mathematics teacher in-service education. In C. Alsina, J. M. Alvarez, B. Hodgson, C. Laborde, & A. Perez (Eds.), *The 8th International Congress on Mathematical Education (ICME 8). Selected Lectures* (pp. 303–321). Sevilla: S.A.E.M. Thales.
Krainer, K. (2012). *Education of mathematics teacher educators. Encyclopedia of Mathematics Education*. Heidelberg: Springer.
Krainer, K., & Zehetmeier, S. (2013). Inquiry-based learning for students, teachers, researchers, and representatives of educational administration and policy. Reflections on a nation-wide initiative fostering educational innovations. *ZDM - The International Journal on Mathematics Education*, *45*(6) (this issue).
Lee, M. M., Chauvot, J., Plankis, B., Vowell, J., & Culpepper, S. (2011). Integrating to learn and learning to integrate: a case study of an online master's program on science–mathematics integration for middle school teachers. *Internet and Higher Education, 14*, 191–200.
Linn, M. (2003). Technology and science education: starting points, research programs, and trends. *International Journal of Science Education, 25*(6), 727–758.
Lipowsky, F., & Rzejak, D. (2012). Lehrerinnen und Lehrer als Lerner – Wann gelingt der Rollen-tausch? Merkmale und Wirkungen wirksamer Lehrerfortbildungen. *Schulpädagogik heute, 3*(5), 1–17.
Maaß, K. (2009). What are teachers' beliefs about effective mathematics teaching? In J. Cai, G. Kaiser, B. Perry, & N.-Y. Wong (Eds.), *Effective mathematics teaching from teachers' perspectives: National and cross-national studies* (pp. 141–162). Rotterdam: Sense Publishers.
Maaß, K., & Doorman, M. (2013). A model for a widespread implementation of inquiry-based learning. *ZDM - The International Journal on Mathematics Education*, *45*(6) (this issue).
Maaß, K., Garcia, F. J., Mousoulides, N., & Wake, G. (2013). Designing interdisciplinary tasks in an international design community. In C. Margolinas (Ed.), *Task design in mathematics education. Proceedings of ICMI Study 22* (Vol. 1, pp. 369–378). Oxford.
Manouchehri, A., & Goodman, T. (2000). Implementing mathematics reform: the challenge within. *Educational Studies in Mathematics, 42*, 1–34.
Matos, J. F., Powell, A., & Sztajn, P. (2009). Mathematics teachers' professional development: processes of learning in and from practice. In R. Even & D. Loewenberg Ball (Eds.), *The professional education and development of teachers of mathematics* (pp. 167–184). New York: Springer.
McDuffie, A. M., & Mather, M. (2006). Reification of instructional materials as part of the process of developing problem-based practices in mathematics education. *Teachers and Teaching: theory and practice, 12*, 435–459.
McKenney, S., & Reeves, T. (2012). *Conducting educational design research*. London/New York: Routledge, Taylor & Francis.
Minner, D., Levy, A., & Century, J. (2010). Inquiry-based science instruction—what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching, 47*(4), 474–496.
Mischo, C., & Maaß, K. (2013). The effect of teacher beliefs on student competence in mathematical modeling—an intervention study. *Journal of Education and Training Studies, 1*(1), 19–38.
Mousoulides, N. (2013). Facilitating parental engagement in school mathematics and science through inquiry-based learning: an examination of teachers' and parents' beliefs. *ZDM - The International Journal on Mathematics Education*, *45*(6) (this issue).
Müller, U. (2003). *Weiterbildung der Weiterbildner* (Vol. 17). Hamburg: Dr. Kovac.
Müller, F. H., Andreitz, I., Krainer, K., & Mayr, J. (2011). Effects of a research-based learning approach in teacher professional development. In Y. Li & G. Kaiser (Eds.), *Expertise in mathematics instruction: An international perspective* (pp. 131–149). New York: Springer.
Nastasi, B. K., Varjas, K., Schensul, S. L., Silva, K. T., Schensul, J. J., & Ratnayake, P. (1998). The participatory intervention model: a framework for conceptualizing and promoting intervention acceptability. *School Psychology Quarterly, 15*(2), 207–232.
National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.
National Research Council (2000). *Inquiry and the National Science Education Standards. A guide for teaching and learning.* Washington, DC: National Academy Press.
Nieveen, N. (2007). Formative evaluation in educational design research. In T. Plomp & N. Nieveen (Eds.), *An introduction in educational design research* (pp. 89–102). Enschede: SLO, Netherlands Institute for Curriculum Development.
OECD. (1998). *Staying ahead: In-service training and teacher professional development*. Paris: OECD.
OECD. (2009). *Creating effective teaching and learning environments: First results from TALIS.* http://www.oecd.org/dataoecd/17/51/43023606.pdf. Accessed 25 July 2013.
Piaget, J. (1980). The psychogenesis of knowledge and its epistemological significance. In: M. Piattelli-Palmarini (Ed.), *Language and learning* (pp. 23–54). Cambridge, MA: Harvard University Press.

Ponte, J. P. (2008). Research and practice: bridging the gap or changing the focus? In M. Menghini, F. Furinghetti, L. Giarcardi, & F. Arzarella (Eds.), *The first century of the International Commission on Mathematics Instruction. Reflecting and shaping the world of mathematics education* (pp. 1908–2008). Roma: Instituto della Enciclopedia Italiana foundata da Giovanni Treccani.

Ponte, J. P., Matos, J. F., Guimaraes, H. M., Leal, L. C., & Canavarro, A. P. (1994). Teachers' and students' views and attitudes towards a new mathematics curriculum: a case study. *Educational Studies in Mathematics, 26*, 347–365.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teachers' learning? *Educational Researcher, 29*(1), 4–15.

Robert, A. (2009). Learning in and from practice: comments and reflections. In R. Even & D. Loewenberg Ball (Eds.), *The professional education and development of teachers of mathematics* (pp. 227–230). New York: Springer.

Rocard, M., Csermely, P., Jorde, D., Lenzen, D., Walberg-Henriksson, H., & Hemmo, V. (2007). *Science education now: A renewed pedagogy for the future of Europe*. Brussels: European Commission.

Ross, J. A., McDougall, D., Hogaboam-Gray, A., & LeSage, A. (2003). A survey measuring elementary teachers' implementation of standards-based mathematics teaching. *Journal for Research in Mathematics Education, 34*(4), 344–363.

Schaumburg, H., Prasse, D., & Blömeke, S. (2009). Implementation von Innovation in der Schule. In S. Blömeke, T. Bohl, L. Haag, Lang-Wojtasik, & W. Sacher (Eds.), *Handbuch Schule*. Bad Heilbrunn: Julius Klinkhardt.

Schoen, H., Cegulla, K., Finn, K., & Fi, C. (2003). Teacher variables that relate to student achievement when using a standards-based curriculum. *Journal for Research in Mathematics Education, 34*(3), 228–259.

Schoenfeld, A. & Kilpatrick, J. (2013). A U.S. perspective on the implementation of inquiry-based learning in Mathematics. *ZDM - The International Journal on Mathematics Education*, *45*(6) (this volume).

Stein, M., Smith, M., Henningsen, M., & Silver, E. (2000). *Implementing standards-based mathematics instruction: A casebook for professional development*. New York: Teachers College Press.

Stillman, G. (2013). Implementation of IBL in Europe from an Australasian perspective. *ZDM - The International Journal on Mathematics Education*, *45*(6) (this volume).

Swan, M. (2006). *Collaborative learning in mathematics: a challenge to our beliefs and practices*. London: National Institute for Advanced and Continuing Education (NIACE) for the National Research and Development Centre for Adult Literacy and Numeracy (NRDC).

Takahashi, A., & Yoshida, M. (2004). Ideas for establishing lesson-study communities. *Teaching Children Mathematics*, *10*(9), 436–443.

Thompson, M., & Wiliam, D. (2008). Tight but loose: a conceptual framework for scaling up school reforms. In C. Wylie (Ed.), *Tight but loose: Scaling up teacher professional development in diverse contexts* (pp. 1–44). Princeton: Educational Testing Service.

Tirosh, D., & Graeber, A. O. (2003). Challenging and changing mathematics teaching practices. In A. J. Bishop, M. A. Clements, C. Keitel, J. Kilpatrick, & F. K. S. Leung (Eds.), *Second international handbook of mathematics education* (pp. 643–688). Dordrecht: Kluwer.

van den Akker, J., Gravemeijer, K., McKenney, S., & Nieveen, N. (2006). Introducing educational design. In J. van den Akker, K. Gravemeijer, S. McKenney & N. Nieveen (Eds.), *Educational design research* (pp. 3–7). Oxford: Routledge Chapman & Hall.

Wake, G., & Burkhardt, H. (2013). Understanding the European policy landscape and its impact on change in mathematics and science pedagogies. *ZDM - The International Journal on Mathematics Education*, *45*(6) (this issue).

Walker, D. (2006). Towards productive design studies. In J. van den Akker, K. Gravemeijer, S. McKenney, & N. Nieveen (Eds.), *Educational design research* (pp. 8–14). Oxford: Routledge Chapman & Hall.

Wilson, M., & Cooney, T. J. (2002). Mathematics teacher change and development. The role of beliefs. In G. C. Leder, E. Pehkonen, & G. Törner (Eds.), *Beliefs: A hidden variable in mathematics education?* (pp. 127–148). Dordrecht, Boston, London: Kluwer.

Winter, H. (1989). *Entdeckendes Lernen im Mathematikunterricht: Einblicke in die Ideengeschichte und ihre Bedeutung für die Pädagogik*. Braunschweig: Vieweg.