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Designing inquiry-based teaching at scale: Central factors for implementation

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In this paper, we describe and discuss a recent attempt to implement inquiry-based mathematics teaching in Danish compulsory school. After a description of the project and an example of the teaching sequences involved, we will introduce a framework for understanding implementation issues in mathematics education, and use this framework to discuss the problems and potential that our project might encounter when it is considered part of a larger implementation of inquiry-based teaching in Danish mathematics education. We found at least three critical factors for implementation: stakeholders, teacher resources, and the balance between well-prepared and more open teaching materials.

Keywords: Implementation, inquiry-based mathematics, teacher development.

Introduction: Implementation and inquiry – a story of potential without impact

This paper addresses the implementation of inquiry-based teaching in mathematics. The idea of developing an investigative and problem-oriented approach to teaching mathematics is not new. Even though the discourse around inquiry-based mathematics teaching only dates back to the late 1990s (National Research Council, 1996), the goal of refocusing mathematics education to practice where students are actively investigating and developing mathematical content at play dates back much further (e.g., Dewey, 1938; Freudenthal, 1991; Papert, 1980). Crucial for bringing about changes to mathematics education is dissemination of experiences and processes to a larger group of schools and teachers. This calls for large scale and long-term capacity building providing pedagogical support for teachers so that they can develop the repertoire of skills and understandings required to teach for inquiry-based mathematics. Furthermore, a sustainable impact depends on a good balance of internal and external resources and support (Krainer & Zehetmeier, 2013; Schoenfeld & Kilpatrick, 2013).

More recently, several European development projects have focused on articulating, testing, and implementing inquiry-based approaches to teaching mathematics, science, and engineering (<http://www.primasproject.eu>, <http://www.fibonacci-project.eu>).

These projects have generally reported positive results showing the potential of inquiry-based approaches to teaching mathematics. However, despite the fact that Denmark participated in a

number of these projects, the findings have not given rise to significant changes in the teaching of mathematics at scale (Mogensen, 2011; Østergaard, Sillasen, Hagelskjær, & Bavnhøj, 2010). With this in mind, the Danish government has initiated a three-year project called KiDM (Quality in Danish and Mathematics Education) focused on developing the quality of teaching in both mathematics and first language (Danish).

One of the goals in the KiDM project is to identify and investigate the enablers and constraints for a large-scale implementation of inquiry-based mathematics teaching. This will be addressed in the present paper, where we describe the inquiry-based activities from KiDM and report on how they are received by the teachers, in order to plan and support the implementation. Using a framework for implementation research (Century & Cassata, 2016), we then try to pinpoint important stakeholders and factors that support, hinder, and alter the implementation of the activities of KiDM. In order to discuss problems, potentials, and relevant foci for KiDM as a large-scale implementation project.

Description of “Better Quality in Danish and Mathematics” (KiDM)

KiDM is a three-year, design-based research and development program named “Kvalitet i Dansk og Matematik” (Better Quality in Danish [first language] and Mathematics); its aim is to make the teaching in Danish compulsory school more inquiry-based. The program involves (1) surveying the literature on inquiry in teaching mathematics and Danish, (2) developing inquiry-based teaching activities for a four-month mathematics teaching approach for 4th and/or 5th grade implemented at 107 schools, and (3) testing the effect of the intervention with a Random Controlled Trial. The control schools and intervention schools are randomly selected with respect to geography, size and ethnicity. They participated with 2-4 classes each, the intervention concerns all lessons in mathematics for a whole semester. The control schools only participated in the tests.

Initial investigations and design principles

The literature survey (Dreyøe, Larsen, Hjelmberg, Michelsen, & Misfeldt, 2018) as a preliminary investigation of KiDM, was conducted to gain insight into the most important issues and main concerns associated with Inquiry Based Mathematics Education (IBME). A systematic search of six of the highest-ranked journals led to five important themes/issues: 1) The literature survey stresses that *communication in the mathematics classroom* should be facilitated as open, inquiring, and related to the students’ activities with a starting point in the students’ prior knowledge. 2) *Mathematical skills and competences* are critical to participation in inquiry-based teaching. The modeling view of problem activities especially holds the greatest learning potential for students in inquiry-based teaching. Inquiry-based teaching has a positive impact on students’ mathematical creativity. 3) The students should be allowed to *move in and out of the mathematical domain*, and hence it is important to use a wide spectrum of activities in teaching. This requires students to be flexible thinkers and prepares them to cope with situations outside of school. Furthermore, the literature survey contained examples of and knowledge about both 4) *tools and resources for planning and implementing inquiry-based learning*, and 5) *professional development and collaboration*. In relation to planning (4), the literature survey suggested that teachers should try to predict the students’ answers and prepare general and specific questions to scaffold, extend, and

promote the students' ability to generalize mathematical ideas. Regarding development and collaboration (5), it is worth noting that any change to a teacher's approach is a lengthy process. By utilizing pre-planned teaching units, one can contribute to a teacher's ability to reflect on how IBME differs from his/her own approach to teaching.

Apart from surveying the literature, we also interviewed six supervisors in mathematics prior to developing the specific designs in KiDM (Michelsen et al., 2017). Diplomas (60 ECTS) in mathematics supervision have been available since 2009, and many schools have a local supervisor in mathematics who initiates changes and supervises fellow teachers. The supervisors are organized in a national network. The interviews revolved around similar themes and to the need for supporting teacher-teacher and student-student collaboration – “We need time to cooperate inventing and exploring”.

From the above, we formulated three principles which implications were important for the didactical intervention of the design for KiDM:

- Principle 1: An exploratory, dialogical, and application-oriented teaching method with room for student participation increases the effect of the student's understanding of mathematical concepts and develops appropriate ways of working.
- Principle 2: In order to enhance motivation and learning, we prioritize that the students' experience of the teaching and the content should be meaningful both from an internal mathematical perspective and from the perspective of the situation of application/inquiry.
- Principle 3: An exploratory, dialogical, and application-oriented teaching approach with room for student participation increases the possibility of implementing mathematical competences.¹

To assess the students' development of mathematical concepts and mathematical competences related to inquiry-based teaching, a pre- and post-test was used in intervention schools and control schools; student and teacher surveys were also conducted focusing on changes in the students' motivation and experiences and the teachers' extent of implementation and experiences, respectively.

The intervention

The inquiry-based mathematics intervention was developed in collaboration with school teachers, supervisors in mathematics, teacher educators, researchers, and professors in an iterative process during which the intervention was tested in a number of cycles in special development schools. The intervention was then tested in a pilot study in 14 schools and adjusted before the actual program began. The program runs for three subsequent semesters in the years 2017-2018. The results for the entire program are expected in 2019.

¹ Mathematical competences (Niss & Højgaard, 2011) is a key concept in the Danish curricular standards.

The KiDM intervention consists of a website that contains a detailed teacher's guide and accompanying student pages with various student activities that take into consideration students' prior experiences, students' opportunity for participation and appropriate ways of working with exploration, applications and mathematical competences especially communication, reasoning, and modeling (principle 1, 2 and 3). In addition to activity descriptions, the teacher's guide also contains specific instructions on how the activities should be introduced, what hints can be given along the way, and how the collective discussion should be designed. The activities are designed to be open for the pupils to engage in mathematizations on a number of different levels. One example of such an activity is to count the number of books in the local library, where the pupils are invited to develop strategies for addressing this question in a structured manner. In Figure 1 we see the activity "How many knots?", where students produce their own data sets by tying knots on a string. The students start by tying as many knots as they can in one minute. Afterwards, every student must count how many knots each have made. In groups of 3–4, students must make charts of the numbers. The assignment is: "If a man comes through the door and asks how many knots a student in this class can tie in one minute, what could you tell him?"



Figure 1: Strings from the activity "How many Knots?"

In the above example, the students' participation is crucial; they create and use their own data. In a meaningful, explorative way of working they get the opportunity to reason about the data, communicate their result by developing their own model.

All supervisors and teachers in the intervention are required to participate in three project meetings during the semester; they are also required to participate in three group meetings with all school mathematics teachers. All the meetings are clearly facilitated in detail on the website, where short video clips are viewed and discussed in the group meetings. Finally, there is an evaluation sheet that must be completed after each meeting. The group meeting focuses on the establishment of IBME teaching, the action phase in IBME teaching, and the validation phase in IBME education. For instance, the teachers and the supervisors reflected on the validation phase of the lessons they have tried out. The supervisor in mathematics is essential for the implementation by arranging, facilitating and evaluating these structured meetings. Lastly, the intervention teachers, supervisors, and, if possible, the headmasters participate in an all-day introductory meeting focused on the intervention, including both didactical and practical organization of the project, and an all-day evaluation meeting at the regional university. During the intervention, one teacher educator or one researcher will visit the school; this visit may focus either on observation of lessons or participation

in a group meeting or project team meeting. The schools receive a stipend for each class participating in the project to cover expenses.

KiDM as an implementation project

In the following section, we will provide some concepts from implementation research and try to use them as a lens to investigate KiDM as an implementation project. We build on the definition of implementation research from the work of Century and Cassata (2016,) as: “systematic inquiry regarding innovations enacted in controlled settings or in ordinary practice, the factors that influence innovation enactment, and the relationships between innovations, influential factors, and outcomes” (p. 170). Century and Cassata (2016) provided a description of important factors for the implementation of educational innovations. These factors are related to (1) *the users*, (2) *the broader organization*, (3) *the actual innovation*, (4) *the strategies supporting* its implementation, and (5) *the timewise dimension* of the implementation. In relation to the individual end users, we should be aware that the changes that educational innovation aims for are mediated by the people involved in the implementation process and aimed at their “change”. Century and Cassata (2016) distinguished the characteristics of individuals that build on their relation to the innovation (such as prior experience with the approach) from the characteristics of individuals that exist independently of the innovation (such as willingness to try new things). What Century and Cassata (2016) referred to as organizational and environmental factors are both characteristics of the specific setting (e.g., the classroom, the colleagues at the school) and to the broader ecology it sits in (e.g., the municipality or school district). Furthermore, these factors can also be completely outside the specific school or district (e.g., national policies). We can also distinguish between the actual and the perceived attributes of the innovation. This distinction highlights the difference between the explicit blueprints and detailed plans and the subjective (and often diverse) experiences of using these plans. The last factor that Century and Cassata (2016) discussed is implementation over time. Time is always a factor in the implementation and diffusion of practices and innovations.

Methods and data

The supervisors were responsible for the local implementation of the KiDM project and they were in charge for the evaluation sheets developed by the project, concerns implementation of KiDM, e.g. the explication of the teacher guide and inquiry-based teaching in general, e.g., key issues and challenges. To understand the status and challenges of KIDM as an implementation project we use the lens from Century and Cassata (2016). In the following section, we use the five factors from above to analyze our project. By reviving and coding the free-text information from the supervisors' evaluation sheets that the local supervisors wrote as part of the documentation of the group meetings and project meetings. The sentences (i.e., citations) were categorized first individually by the first and second author of this paper according to the five factors but also in connection to enablers and constraints in implementation. Afterwards the coding was discussed in the whole group.

Characteristics of individual end users of KiDM

The end users of the KiDM project are teachers of mathematics, supervisors in mathematics at the participating schools, and students. Intervention schools were randomly selected according to a

number of parameters, and therefore, we assume that we consider all types of mathematics teachers. However, there was a request that teachers had mathematics as their main subject and teaching experience in mathematics. This request was not met for all schools. Another request was that the school provide a coordinator who is a supervisor in mathematics. Some schools were unable to fulfill this, and their coordinators were participating teachers or the headmaster. We take into consideration the heterogeneity of the teachers by being very explicit with detailed plans in the teacher's guide. However, in terms of explication, there were still challenges, "It is very hard for a teacher who doesn't have math as their main subject to read the teacher's guide". In a similar vein, "Preparation of the activities is hard work. We are only two educated math teachers in a group of six teachers, so we have to do most of the work". Others found the material to be very explicit, "The didactic description is very thorough. A teacher who doesn't have math as their main subject would be able to teach if he had the time and opportunity to read the description".

The teachers are a critical part of the end users and the data we currently have suggest that one important aspect of the project's ability to satisfy this group is to provide enough information so that the instructions are clear (since inquiry-based approaches are new to some of the teachers) while not providing so much information that the workload becomes too great.

Organizational and environmental factors

The project is funded by the Danish Ministry of Education and supported by the Danish Union of Teachers. The school receives a stipend, which covers extra time for preparation and participation in meetings; this is important for the participants, "We have spent a lot of time reading the teacher's guide. If there had been no extra time given in the project, we would not be able to use such an extensive teacher's guide".

The intervention is planned in accordance with the national curriculum, yet some of the participants questioned the extent of this, "Do we meet the needs for the National Test?" and "Are the curriculum in play equivalent to half a year's work?"

As described above, the supervisors play an important role at most of the participating schools since they organize the meetings and local progress in the project. The project meetings are important for cooperation and for shift in collective attitudes: "We have cooperated far more than we have ever done", "Wonderful to 'nerd' with mathematics at the meetings", and "It has been liberating to be able to engage in discussions about mathematics and didactics at the group meetings".

The important organizational factors are economic resources/time, legislative support, and collaborative structures. Furthermore, we can see that the supervisors in mathematics becomes critical as the person who plans and facilitates the activities.

Attributes of the innovation

The degree of specification of what teachers and students must do in KiDM is high. The operationalization is not left to the teachers to perform by themselves. This tight scaffolding can be seen as critical to the success of KiDM. On the homepage, the teachers have access to a teacher guide that includes specific questions to ask in all phases of the activities, the aims of the activities, and agendas for all project meetings and group meetings. The agenda includes questions for

discussion, links to short videos to watch and discuss, and tasks to solve and discuss. The teacher's guide has some flexibility in the material, for example, to differentiate between 4th and 5th grade or to include students who are especially talented in mathematics.

The teachers in the project have varying attitudes toward this detailed and tight operationalization; some teachers said that having a very strict teacher manual helped them in the beginning, but at the end of the intervention, some of the teachers did not follow the manual entirely.

Implementation support strategies

The implementation strategies in KiDM are very broad. One important strategy is the meetings held at the local schools, where the focus is on discussion, operational planning, and professional development among mathematics teachers at the school. There were various comments about the idea that the teachers in the project must present their work at the larger mathematical group meeting at the local schools – “It does not work. You cannot involve the entire school in something that three teachers participate in” – but most of the teachers responded very positively about these meetings – “We have discussed teaching and reflected about teaching and learning much more than we usually do. We hardly ever say, ‘How about page 87?’” The supervisor has an important role in these meetings because he/she must facilitate these meetings. If these meetings are not successful, it will affect the implementation at the school. The supervisor in mathematics can therefore be seen as a *change agent*. In addition, the KiDM teachers are given more time than usual for their lesson preparation and their extra meetings, which can also be considered an implementation strategy in the hopes that this additional resource can support further development of teachers.

Implementation over time

It is not yet possible to determine whether the teachers' methods of inquiry-based teaching have been implemented, as the project is still ongoing. At this point, it is not possible to determine whether the teachers are at a specific developmental stage (from awareness to initial adoption to sophisticated innovation), but some teachers have stated that they already have ideas for how they will implement an inquiry-based approach in the future: “We have applied for a workday where all the math teachers will try to formulate a strategy for how to implement inquiry-based mathematics” and “All classes from the 1st to the 5th grade receive one extra hour per week. This hour must be used for inquiry-based mathematics”. However, there are other variables that also come into play, such as the involvement of school leadership: “It is a turning point, the head of school is interested”, or “We don't have a final agreement for the continuation of the work with the head of school yet”. The involvement of the mathematics group at the school is also important over time: “Despite the skepticism at the start (from the teachers not participating in the project), everybody is much more positive about the project as well as discussing didactics topics at the meetings”.

Implementation as core stakeholders, resources, and an act of balancing

In answering our question about enablers and constraints for KiDM considered as a large-scale inquiry-based project in Denmark, we see at least three factors that are critical, namely core stakeholders, balance, and resources. The first is the existence of core stakeholders in this change; Denmark is lucky to have a relatively newly educated group of supervisors in mathematics that can

act as such. In a survey initiated by the Danish Ministry of Education (Mogensen, Rask, Lindhardt, Østergaard, & Rostgaard, n.d.), supervisors seem to be very influential in implementing government initiatives. The supervisors and group meetings are crucial organizational factors in KiDM. Hence, the supervisors in mathematics have the potential to act as change agents in future large-scale implementations. The second factor that we see as critical is the existence of time and money to support the work. This is stressed repeatedly by the participants. However, rather than just providing more money to the schools, we can see that the visibility of the project resources for the teachers involved is critical, at least in our case. Therefore, necessary resources should be available to the end users (in this case, the teachers). The last factor is that of *balance* between well-prepared material/structures and the freedom to change and modify. In this project, we have been quite precise about what has been prepared, and this has worked particularly well when teachers and supervisors adopted the approach and made it their own.

These three themes have been in the way that we describe the envisioned output and evaluation criteria of the project and hence as a part of the theory of change of the project.

References

- Century, J., & Cassata, A. (2016). Implementation research: Finding common ground on what, how, why, where, and who. *Review of Research in Education*, 40(1), 169–215.
- Dewey, J. (1938). *Logic: The theory of inquiry*. New York, NY: Holt.
- Dreyøe, J., Larsen, D. M., Dreier Hjelmberg, M., Michelsen, C., & Misfeldt, M. (2018). Inquiry-based learning in mathematics education: Important themes in the literature. In E. Norén, H. Palmér, & A. Cooke (Eds.), *Nordic Research in Mathematics Education: Papers of NORMA 17* (pp. 329–337). Stockholm, Sweden: Swedish Society for Research in Mathematics Education.
- Freudenthal, H. (1991). *Revisiting mathematics education. China lectures*. Dordrecht, The Netherlands: Kluwer.
- 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 Mathematics Education*, 45(6), 875–886.
- Michelsen, C. Dreyøe, J., Hjelmberg, M., Larsen, D., Lindhardt, B. & Misfeldt, M. (2017). *Forskningsbaseret viden om undersøgende matematikundervisning* [Research based knowledge about inquiry-based mathematics teaching.] Retrieved from http://vbn.aau.dk/files/265214078/Vidensnotat_matematik_2.PDF
- Mogensen, A. (2011). *Point-driven mathematics teaching. Studying and intervening in Danish classrooms*. (Doctoral dissertation). Roskilde University. IMFUFA-tekst: i, om og med matematik og fysik, No. 484. Retrieved from <http://milne.ruc.dk/imfufatekster/pdf/484web.pdf>
- Mogensen, A., Rask, L., Lindhardt, B., Østergaard, K., & Rostgaard, P. (n.d.). Fagteamsamarbejde og matematikvejlederfunktion i grundskolen. [Subject specific team collaboration and the function of math-councillors in primary school.] København, Undervisningsministeriet.
- National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.
- Niss, M., & Højgaard, T. (2011). Competencies and mathematical learning. Ideas and inspiration for the development of mathematics teaching and learning in Denmark. Roskilde: Roskilde University. IMFUFA-tekst: i, om og med matematik og fysik, No. 485. Retrieved from https://pure.au.dk/portal/files/41669781/THJ11_MN_KOM_in_english.pdf

- Østergaard, L. D., Sillasen, M., Hagelskjær, J., & Bavnhøj, H. (2010). Inquiry-based science education – har naturfagsundervisningen i Danmark brug for det? [Inquiry-based science education – is it needed for Danish STEM teaching?]. *MONA*, 2010(4), 25–43.
- Papert, S. (1980). *Mindstorms. Children, computers and powerful ideas*. New York, NY: Basic Books.
- Schoenfeld, A. H., & Kilpatrick, J. (2013). A US perspective on the implementation of inquiry-based learning in mathematics. *ZDM Mathematics Education*, 45(6), 901–909.