Mathematics Education Meets Development Education

The Competency 'Mathematical Modelling' combined with Global Skills and Competencies in a Secondary School Project in Germany

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Abstract
This article describes a scientific and practical journey through the worlds of mathematics education and development education/global education. It explores one link in detail: critical mathematics education and the competency 'mathematical modelling' in theory and practice. It describes a case study of a secondary school in Baden-Württemberg, Germany, based on a model of critical research. A central theme is the value of a holistic, self-organized learning process in which global and mathematical competencies and skills are combined. The research identifies the value such a process provides in helping students understand their role in a global society, including recommendations for schools, policy, and research.

Keywords: Development education, global education, critical mathematics education, education for sustainable development, critical research, global skills and competencies, mathematical competencies, mathematical modelling, modelling process, critical thinking, emancipation, empowerment, global justice, social justice, democracy, global issues, poverty

1. Introduction

This article deals with the fascinating question: What does mathematics education have to offer in times of globalization? It explores the potential role of mathematical tools in perceiving global key issues and threats such as poverty, climate change, conflicts, pandemics, and their interconnectedness. Can the world of mathematics help to understand and interpret the real global world around us, and if yes, to what degree? And on the other hand, what can development education contribute to a modern mathematics education that is relevant to everybody's life in a more globalized society?

Even though we are surrounded by figures, numbers, and statistics that describe and reflect global phenomena such as gross domestic product (GDP), the human development index (HDI), carbon footprint, or the happy planet index, we find very few examples of learning processes including a global dimension in mathematics. This article contributes to closing this gap. It is based on a case study that evolved from my professional experience as a mathematics teacher in Lesotho, and from my later work at EPiZ, an institution based in southern Germany that supports teachers, students, and educators in developing and implementing concepts of development education. My involvement in development education and mathematics education helped me to realize that these two fields of education hold a great potential for mutual inspiration and synthesis.

The article can be described as a scientific and practical journey through the worlds of mathematics education and development education/global education. In the second section a literature review at the intersection of development education, global education, and mathematics education will show potential links, identifying and concentrating on critical mathematics education including the competency 'mathematical modelling'. The third and fourth sections give an overview of the methodology and findings regarding a case study at an individual school, which explored one link in detail, answering the following main research question: How can the acquisition of mathematical competencies, especially competency in 'mathematical modelling', encourage students (grade 8, age 14–15 years) in secondary schools in Germany to think about their role in a global society? Sub-questions evolved from aspects that always need to be considered in fruitful learning processes in development education, in order to meet the wants and needs of the learners and create appropriate learning conditions with regard to content, methods, and framework conditions:

- What do students and teachers think are potential issues when students are asked to link their everyday life with global issues based on their mathematical competencies and the requirements of the curriculum? (Sub-question 1)

- What do teachers and students think are favourable conditions for a fruitful learning process in a modelling project focusing on global issues? (Sub-question 2)

A school project (case study, section 3) was designed as a learning opportunity for students (Lang-Wojtasik, 2011: 246), which may contribute to preparing them for life in a global society. The last section summarizes the results and translates them into recommendations for schools, policy, and research.

2. Mathematics education meets development education

Development education, global education, and mathematics education

Development education (DE) and **global education** (GE) encompass clusters of adjectival educations that are closely related and described differently depending on the local, regional, or national context. These terms have different meanings in differing educational contexts. In the UK, DE has been described as 'an approach to learning about global and development issues through recognizing the importance of linking people's lives throughout the world' (Institute of Education, DERC, 2011: 1). DE emphasizes the importance of critical thinking and aims to challenge stereotypes. It seeks to equip people with skills that will enable them to act towards a more just and sustainable world (*ibid.*: 1).

Influential to this approach is the literature on the importance of critical thinking and critical pedagogy, stimulated, for example, by the question of Andreotti (2006: 41): Whether and how to address the economic and cultural roots of the inequalities in power and wealth/labour distribution in a global complex and uncertain system. This influenced this author to put emphasis on 'critical thinking and reflection of the power relations which influence and shape our lives in a globalized world' (Schell-Straub, 2011: 9).

In the mid-1990s GE emerged in Germany from various pedagogical theories, including a tradition around the concept of development education, but which had an emphasis on learning about development. GE is now the commonly used term in practice and policy in Germany, although its leading theorists pay tribute to its roots in DE.[1] Three core competencies play a vital role in GE. These are (1) the ability to understand; (2) the ability to value; and (3) the ability to act (BMZ, 2007, see below). GE seeks to address the twofold challenge that is posed by living in a globalized world, i.e., to find orientation for one's personal life as well as to develop a vision for a just and humane global community (Scheunpflug and Schröck, 2002). In this context the focus of GE on self-directed and action-oriented learning is vital.

1 For a detailed history of DE in the German-speaking area, see Scheunpflug and Seitz (1995); for the emergence of GE, see Scheunpflug and Asbrand (2006: 34ff.).

Modern concepts of **mathematics education** (ME) are focused on moving away from mathematics as an end in itself towards a functional perspective on mathematics where learners are enabled 'to use and apply the mathematics they know to address problems that arise in their life and work' (Functional Skills Support Programme, 2007: 21).

According to Cotton (2001: 24), mathematics is a powerful tool in explaining and interpreting the world in which we live: 'Maths both explains and constructs reality within our society'.

Therefore mathematics is an important tool or 'language' in constructing, explaining, and interpreting the globalized world. In this sense, mathematics education is highly relevant for development education and global education. It can, therefore, substantially contribute to giving people orientation for their life and its global-local interconnectedness. As will be shown in this article, mathematics has something to offer for development education, which goes far beyond students calculating the travel distances of a pair of jeans during production or someone's ecological footprint. As the following section will show, critical mathematics education is an educational perspective with remarkable similarities to development education in its history, visions, goals, and socio-political contexts and consequently rich in linking ME and DE/GE.

Critical mathematics education as a link between development education and mathematics education

Critical mathematics education (CME) is a mathematical educational concept of largely international origin that was coined by Ole Skovsmose, one of the most prominent representatives of CME. The expedition described in his book, *Travelling Through Education: Uncertainty, mathematics, responsibility* (Skovsmose, 2005a), is enriched by the author's real travels around the world in which he was inspired by different educational contexts and pedagogues. Even though he does not name it specifically, it is obvious from his account that he also entered the world of DE as he listened to different voices and perspectives from various cultural and political contexts. In part one, 'Mathematics is everywhere' (*ibid.*: 1–47), he raises some basic concerns of CME, which resonate with DE: 'A cultural perspective' (*ibid.*: 13), 'Globalization' (ibid: *cf.*, 25) and 'Mathematics education is critical' (*ibid.*: 38).

A review of recent publications and studies showed remarkable areas of resonance and potential for mutual enrichment. Theorists and practitioners in both mathematics and development education fields have recently reflected on the influences of critical pedagogy and Freirian education within the wider context of educational, social,

and political issues of the twenty-first century. In his article, 'Towards a rethinking of development education', Bourn (2008c: 19) describes present needs for DE:

> Development education as suggested needs to move away from seeing itself as a movement of NGOs and others who have common perspectives, it needs to be a coming together of development theories and theories of learning. It needs to take particular account of the influences of the ideas of Freire and liberation thinking. It needs also to reflect on the role and potential role of education in society. It needs to recognize that learning is not neutral or value-free. Finally it needs to recognize in a broader social and cultural context the impact of critical social theory and post- modernism.

On the side of CME, Skovsmose (2005b: 1) asks:

> Does critical mathematics education embody an obsolete line of thought? Is it just a leftover from an outdated leftist educational movement? If not, what could critical mathematics education mean today and for the future?

These separate rethinking processes hold the potential for 'thinking together' DE and CME, joining of forces to develop learning theories and approaches in cooperation and mutual enrichment, and work towards common visions and goals as described above. Taking up Skovsmose's statement, 'Mathematics is everywhere', one could add 'Development education is everywhere' and ask: What could be on the agenda of an ME and DE enterprise?

One first goal of this enterprise could be a joint reflection of the common ground, **critical pedagogy**, analysing the common roots in the past and transforming them into key principles meeting present challenges of education in a globalized world. In the past, critical pedagogy has influenced scientific communities and shaped the concepts of both DE and CME as the following statements may illustrate.

Tutak *et al*. (2011: 66) describe critical pedagogy as follows: 'Raising questions about "the way things are" and wondering how they might be done differently are the habits of those who embrace a "critical" approach to education'. They see the role of educators in encouraging students 'with critical eye to examine social justice in their world'. In line with Goodman (1992), they emphasize that critical theory in education means 'liberating, enlightening, emancipating, and empowering'. In both concepts the question of self-reflexivity and criticality in teachers' or tutors' attitudes is discussed. The statement by Tutak *et al.* (2011: 67) that:

> [t]he teacher stimulates questioning but does not impose views on students … Forcing learners to engage in critical thinking and action contradicts the nature of critical pedagogy, raising critical consciousness against domination that controls how people think and live

resonates with an implication of global education regarding the need to maintain freedom as formulated by Scheunpflug (in Bourn, 2008a: 21):

> Global learning and education requires that educators treat learners as fully emerging world citizens who come to autonomous decisions. Indoctrination is incompatible with an educator's (or indeed an NGO's or activist's) role in education in a democratic society.

Thus, a first synthesis and common base of CME and DE/GE in the present and future could be described as **mathematics education for global justice**, embracing the commitment to social justice, solidarity, and democracy locally and worldwide. Referring to Scheunpflug (Bourn, 2008a: 19) and Tutak *et al.* (2011: 65), the overall aim of the mathematics education and development education enterprise in formal education could be empowering students with **mathematical and global competencies** needed to create democratic communities embracing social justice in the school. But this would also be with a view to regional, national, and global dimensions, to prepare them to live in a globalized world, in a way that enables them to respond to the challenges of an interconnected world, to take responsibility, and to advocate for global solidarity and social justice.

Theoretical reflections on mathematical and global competencies, especially the competency mathematical modelling, are discussed in more detail in the next section. This is of central importance to the present study, which embraces a learning process where mathematical and global competencies and skills are brought together and applied in an educational setting.

Mathematical modelling in relation to mathematical and global competencies and skills

It is necessary to clarify how competencies and skills in mathematics education and development education are defined or explained, since their definitions vary widely across geographical, educational, and political contexts depending on the underlying political agendas.

According to Weinert (2001: 27),[2] **competencies** are defined in this context as: 'The cognitive skills and abilities inherent in an individual or that can be learned by him or her to solve certain problems, as well as the connected motivational, volitional, and social willingness and ability to successfully and responsibly solve problems in variable situations'. Hence 'competency' is a colourful term that combines and interweaves the facets: skills, understanding, ability, action, experience, and motivation (BMBF, 2007: 72, 73). Weinert's definition is in good agreement with the

2 In a survey commissioned by the OECD, Weinert developed several possibilities to define 'competency'. In 2001 he formulated this definition, which is the most-cited definition in Germany at present.

Organization for Economic Co-operation and Development's (OECD) description of competencies (DeSeCo 2005: 4). **Skills**, following European definitions, are seen as the 'ability to apply knowledge and use know-how to complete tasks and solve problems'[3] and 'general capacities to perform a set of tasks developed through the acquisition of experience and/or training which require more than just knowing about the subject.'[4] Thus, skills can be seen as more than occupational and technical, including transferable skills, skills needed in everyday life, and wider employability skills.'[5] (Bourn, 2008b: 6)

In learning processes, competencies usually merge into each other and can't be distinguished sharply. They are acquired and applied in clusters and described in frameworks, the following three being regarded as most relevant to the concrete situation of this case study at the intersection of DE and ME:

1. The **core competencies in the global development learning area** are an essential part of a German policy paper, 'A Cross-Curricular Framework for Global Development Education in the Context of Education for Sustainable Development' (BMZ/KMK, 2007, referred to in the following as the GDE Framework). The paper is a framework for the development of curricula in the Federal States (Länder) of Germany and specific school curricula. The GDE Framework identifies three core competencies – ability to understand, to judge, to act[6] – which are further subdivided into 11 competencies. The competencies it identifies are highly relevant to the present case, especially the competencies (1) **acquisition and processing of information**, (3) **analysis of the global change**, and (6) **critical reflection and formation of opinions**.

2. The **'global skills'** framework (Bourn, 2008b) was chosen to complement the GDE Framework because it is based on international frameworks[7] and debates, policy initiatives, and practice relevant to global skills. It brings together a range of common skills to demonstrate their relevance and application to living and working in a global society and economy (Bourn, 2008b: 26). The skills are broken down into six **global skills** and **six core skills**. Skills relevant to the present case include in particular: **the ability to understand the impact of global forces on people's lives** (global skill), which can be interpreted as a

3 See www.euro-inf.eu/content/view/16/16.
4 See www.neiu.edu/~dbehrlic/hrd408/glossary.htm.
5 See www.lluk.org.uk/documents/sector_skills_agreement_stage_5_england.pdf.
6 Liberal translation of the core competencies: 'Erkennen, Bewerten, Handeln'. The authors translate them in their English version as: recognition, evaluation, action.
7 For example: CEDEFOP – Future Skills Needs; 21st Century Skills. Online. www.cedefop.europa.eu/EN/news/4045.aspx (accessed 17 August 2011).

broader description of competencies 1, 3, and 6 in the GDE Framework; and **literacy and numeracy** and the **use of IT** (core skills). These two core skills can be subsumed under **mathematical competencies**.

3. As a result of the PISA project, basic **mathematical competencies** have been introduced to school curricula in many countries including Germany, a prominent example of which is the curriculum of Baden-Wuerttemberg. In the PISA Framework (OECD, 2003: 45) there is a clear emphasis on **mathematical literacy**, described as:

   > an individual's capacity to identify and understand the role that mathematics plays in the world, to make well-founded judgements and to use and engage in mathematics, in ways that meet the needs of that individual's life as a constructive, concerned, and reflecting citizen.

   From a DE perspective, one would like to just add one word here: a reflecting 'global' citizen.

During the last three decades, the competency **mathematical modelling** (referred to in the following as modelling) was one of the central topics in mathematics education. Modelling relates the mathematics to the world we live in, called the 'real world' outside of mathematics.

A **modelling process** consists of several **stages**. The starting point is a real problem or situation which might be influenced by many factors and, to speak from a development education perspective, interpreted by different people in different ways. It might be a situation or problem of the global development learning area (poverty, nutrition, health, climate change, etc.). According to the knowledge, goals, and interests of the modelling person, the situation is simplified, structured, and made more precise. This leads to the specification of the problem in terms of language and concepts. Inquiries might be necessary to gather more information and to collect data related to the problem. All this has to be taken into account in choosing the type of mathematical model that is appropriate to address the specified real-world problem. In the next step the relevant objects, data, relations, conditions, and assumptions are translated into mathematics, resulting in a mathematical model. Then mathematical methods and techniques are used to analyse and solve the problem within the mathematical model.

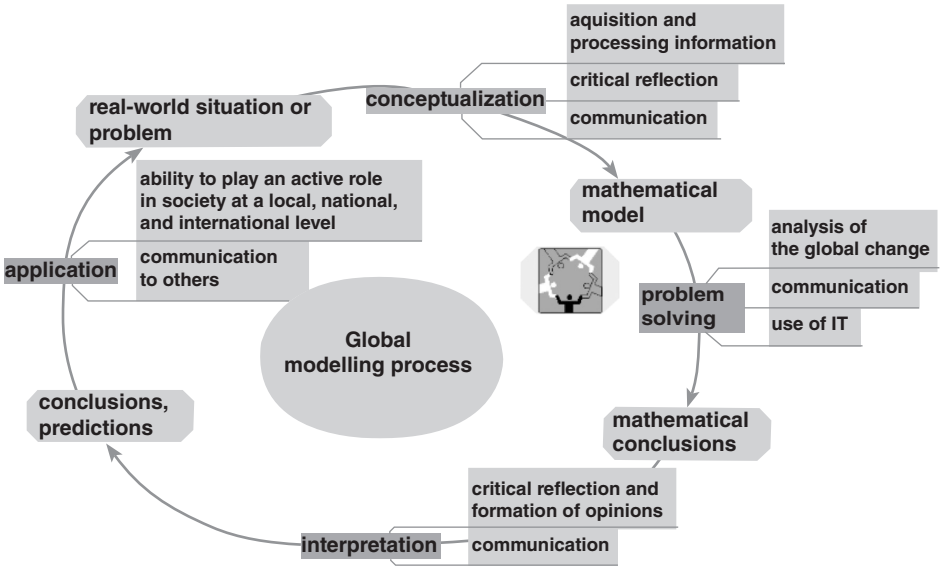
After that the results are translated back into the real situation, and interpreted and tested in relation to the original real-world context: Are the mathematical outcomes reasonable and compatible in relation to the original problem situation? Do they make sense? Are they useful? If not, the whole modelling cycle has to be repeated, modifying the model or changing it completely. Finally, the solution of the real-world

problem can be stated and communicated to others (cf. modelling process described by Blum *et al.,* 2007: 9; Swetz and Hartzler, 1991: 3).

Mathematical modelling competency embraces 'the ability to perform processes that are involved in the construction and investigation of mathematical models' (Blum *et al.*, 2007: 12, 13). From a DE perspective, a critical attitude towards modelling is vital, because 'modelling is often situated in social and political contexts and learning to model should go beyond the merely technical aspects to address its human purposes' and 'most people uncritically "consume" the products of mathematical modelling, without having any understanding of the models used, the assumptions on which they are based, or the general concept of modelling itself' (Greer and Verschaffel, in Blum *et al.,* 2007: 223, 224). This focus on **critical modelling** is a potential area of resonance between ME and DE to be further developed.

Figure 1 shows the stages and processes of a modelling process and how they resonate and interlink with the global mathematical skills and competencies described above. This model of an ideal global modelling process formed the theoretical basis for the case study.

Figure 1: A 'global modelling process' integrating relevant global skills and competencies



3. The case study: Context, strategy, and specific methods

This section aims at highlighting the context, the research strategy, derived from a model of critical research and specific methods of the case study. The research was situated at the intersection of mathematics education (ME) and development education (DE) and at the interface between social, political, and pedagogical theories and approaches described in the previous section on the one side and a local school context with students and teachers, their socio-cultural backgrounds, their hopes and aspirations in school and in their real life, their learning and teaching wants and needs, on the other. A small-scale case study was chosen as an appropriate strategy of inquiry in order to 'advance an action agenda for change' (Wilkinson, 1998, as cited by Cresswell, 2009: 10) by trying to identify criteria for an effective learning process focused on global issues and incorporating functional mathematical skills, and to 'engage the participants as active collaborators in their inquiries' (*ibid.*: 10).

School context and curriculum

The case study took place in the Realschule Neuffen, a secondary modern school situated in the city of Neuffen, Baden-Württemberg, Germany. In the curriculum of Baden-Württemberg, revised in 2004 (Ministerium für Kultus, Jugend und Sport Baden-Württemberg, 2004), a number of text passages were relevant to the pedagogical aims of the project.

In the **introductory chapter** of the curriculum, it is stated why the revision of the curriculum was necessary. One reason mentioned is 'the economic and political growing together of the world', which is seen as 'increas[ing] the number of relationships in which the people engage' (*ibid.*: 8). The description of **attitudes** that students should assimilate includes aspects of global education:

> Students are widening their horizon beyond the neighbourhood, the town, the republic towards neighbouring countries, Europe, the World – with the freedom of global citizenship they are acquiring a sense of the nature of their own people, their own language, their own nation. (*ibid.*: 12).

The **methodological principles** described there correlate with self-directed learning: 'The students participate in the planning of the learning process, the selection of occasions and topics. This enhances their participation in classwork' (*ibid.*: 16).

The curriculum opens up spaces for specific school profiles and cooperation with external partners. It encourages schools to define answers to central questions such as: How do we encourage the participation of parents and external partners in the development and implementation of the curriculum? (*ibid.*: 18).

These overarching aims and principles are complemented by **subject-specific syllabi**.[8]

When comparing the guiding principles in the two subjects mathematics and geography, economics, social studies (GES – a combination of subjects taught together in Baden-Württemberg), it is remarkable how they fit together like matching and sometimes overlapping puzzle pieces. The main similarities and complements are as follows:

1. Learning in mathematics means an opportunity to describe conditions of the real world, while GES is based on a holistic understanding of living spaces in the world.
2. In mathematics one main intention is to enable students to apply their mathematical skills to solve problems of a changing world. To gain an understanding of the changing world, including globalization processes, is one of the objectives of GES.
3. The underlying values are complementary, except the value 'responsibility', which is mentioned in both subjects.
4. The mathematics syllabus describes competencies needed to translate the real world into the mathematical world and vice versa as well as competencies needed to solve problems within the mathematical world. The GES syllabus comprises competencies needed in a globalized world for understanding and analysing processes. It stresses the importance of showing ways of participation and political action.
5. The importance of critical reflection can be found both in mathematics and GES, mainly in connection with the critical use of the internet.
6. Both syllabi refer to the use of modern media and IT training.

Although an interdisciplinary approach is supposed to interweave all pedagogical practice, there is no particular hint in either syllabus to the effect of encouraging a combination of mathematics and GES. This study explored the pedagogical benefit of filling this missing link following basic principles of CME.

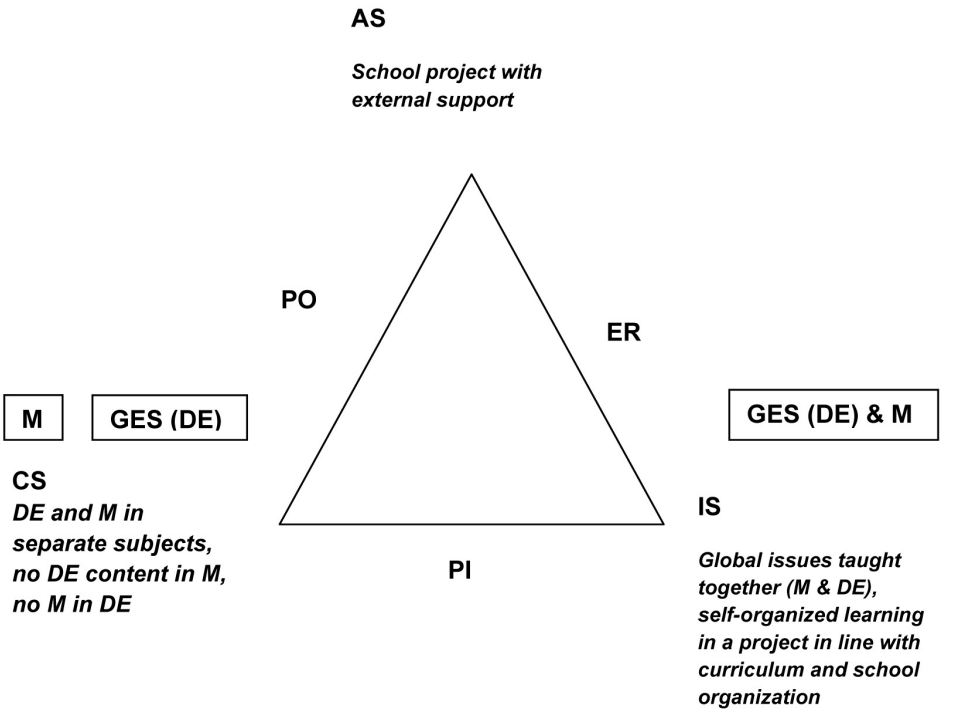
Model of critical research

In accordance with the focus on CME, the case study followed and adapted a model of critical research (*cf.* Skovsmose and Borba in: Valero and Zevenbergen, 2004: 207–26). The starting point was the school situation (*current situation*, CS)

8 The term curriculum is used as an overarching concept; the term syllabus describes specific content related to **one** subject.

with 'problematic' features: mathematics (M) and GES lessons containing DE issues were taught independently following their respective syllabi and learning objectives. On the basis of theoretical considerations (see above) and in the process of a project team discussion (teachers and researchers), *pedagogical imagination* (PI) evolved and an *imagined situation* (IS) to fill the missing link was constructed: a self-organized, interdisciplinary, holistic learning process on global issues, meeting the interests and learning needs of the students, which fostered the development of mathematical and global skills and encouraged the students to reflect on their role in a global society, in line with the curriculum and the school organization. The project team proceeded to create an artificial or *arranged situation* (AS) adapted to the framework conditions prevailing at the school by proposing and then implementing a joint school project involving interdisciplinary teaching, learning, and researching (*practical organization*, PO). The learning process was strongly supported by the researcher, who was involved in the learning process. In a reflective process (*explorative reasoning*, ER) between teachers, researchers, and students, the results of the AS were analysed in the light of the IS and based on data collected by a variety of methods. Figure 2 summarizes the model of critical research adapted to this case.

Figure 2: Model of critical research adapted to the case (cf. ibid: 216)



Arranged situation and specific research methods

During the interdisciplinary school project in grade 8, Realschule Neuffen in Baden-Württemberg, the mathematics and GES teachers selected a period of two weeks and reserved 14 lessons in total for the project in a class with 31 students. The lessons took place during normal mathematics or GES classes according to the school timetable. The pedagogical objectives correlated with the main research question and addressed aspects of the syllabus:

By the end of the project the students will have …

- *explored a topic related to the main topic of '**poverty**', chosen according to their interests in a participatory group process*
- *applied and further developed their global and mathematical competencies, especially competency in 'modelling'*
- *applied and further developed their methodological competencies, especially the critical use of the internet*
- *gained information about ways of participation and action*
- *reflected on how their insights relate to their own role in a global society.*

These objectives had one overall aim: to show the students that mathematical competencies are useful for their real life in a globalized world.

The project was subdivided into four sequences with specific research methods as shown in Table 1.

Table 1: Sequences and research methods of the case study

Sequence	Research methods
1. **Preparing the ground**, four lessons, aimed at introducing the main topic 'poverty' (provided as an option in the curriculum of GES and chosen by the teachers) to the students; enabling the participants to grow together as a research community and defining their roles as teachers, learners, and researchers; compiling learners' relevant previous knowledge and competencies; choosing sub-topics (they were **health, family, nutrition/hunger, waste, rainforest**) and establishing working groups according to the learners' interests and questions; and, finally, introducing them to the use of the multimedia room and internet resources	A **semi-structured questionnaire** for the students at the end of this sequence to gather qualitative and quantitative data on the students' perspectives regarding their: – interests in the topic and chosen sub-topic – perspectives concerning the learning process of the first sequence **Participant observation** by teachers and researchers

2. **Self-organized learning in groups,** six lessons, working on questions related to their topics in groups, using their mathematical competencies and internet resources, being supported by teachers and researchers, students periodically reflecting on their learning progress	'**learning graph**', students plotting their progress (or regress) in a diagram, the X axis representing the timeline and the Y axis representing their perceived progress/regress in mathematical and topic-related competencies **Participant observation**
3. **Presentations of group work and relevance of results,** four lessons 3.1. Students **producing** two types of **posters**: – The first poster showing their topic, their questions concerning the topic, and their work in the form of texts, diagrams, calculations, major results, and possibly questions they could not answer or new questions found during the group work – The second 'action poster', showing activities undertaken towards resolution 3.2. **Gallery walk along the posters**, additional task for students to comment on Post-its on all the 'action posters', showing links between poster content and their everyday life, encouraging reflections on their role as global citizens 3.3. **Plenary session**, teachers, researchers, and students discussing the Post-its and reflecting about their role in a global society, teachers and researchers commenting on the students' suggestions, and offering additional information about possible actions to overcome global poverty	**Analysis of posters, Post-its, and video** of the gallery walk and the plenary session **Participant observation**
4. **Reflection on the whole learning process** All the participants (researchers, teachers, students) sharing their insights in focus groups, guiding questions derived from research questions focusing on selected and potential issues, mathematical skills (applied, gained), criteria for the learning process (competencies of teachers, learning environment, learning methods, participation of students, outcomes, possible follow-up activities, etc.), and framework conditions (school organization, time frame, workload of students, etc.)	**Small focus groups** (Greenbaum, 1998): 1. four **student focus groups** 2. one **focus group** with teachers and researchers

4. Explorative reasoning: Findings and insights

On the last day of the project the researcher, the teachers, and the students started an explorative reasoning process (ER) by looking through the lens of the arranged situation (AS). In this section this analysing process is continued. The main findings are depicted along the lines of the research questions, drawing on the model of critical research described above.

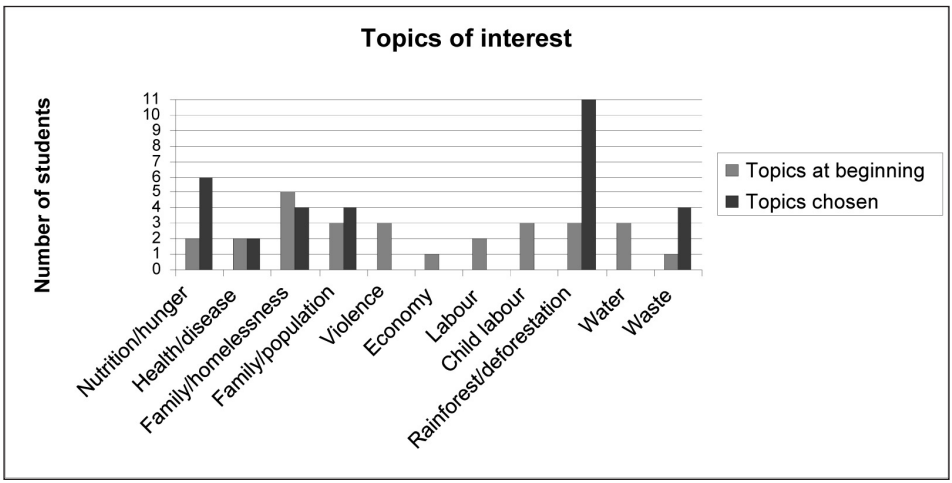
Findings with regard to the first sub-question: What do students and teachers think are potential issues when students are asked to link their everyday life with global issues based on their mathematical competencies and the requirements of the curriculum?

Two limitations relevant to this question have to be pointed out:

1. The teachers restricted the main topic of the school project to 'poverty'. Therefore only interests linked to this issue can be discussed.
2. Photographs were used in the introductory lesson in order to help students find interesting topics. The selection certainly influenced the students in their choice of topics.

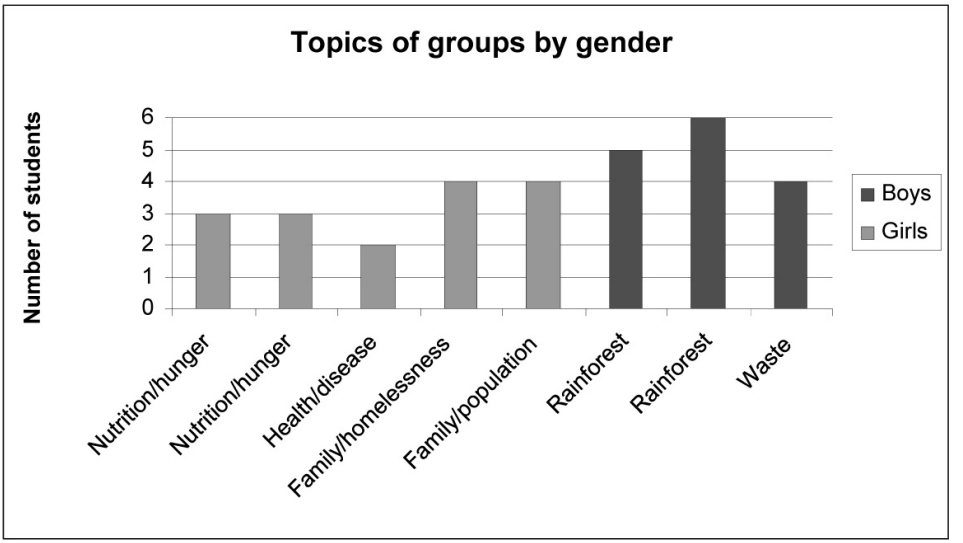
Figures 3 and 4 summarize the students' choices, which they derived from photographs and expressed in keywords in the introductory lesson as well as the topics eventually chosen by the groups at the end of sequence 1. They had been asked to choose according to their interests. Their choices can therefore be said to reflect their interests, bearing in mind the limitations mentioned above.

Figure 3: Topics of students' interest[9]



9 The total number of students at the beginning was 28 (some were absent). All students of the class participated and the total number of work group participants was 31.

Figure 4: Topics of work groups



The qualitative analysis of the reasons for their choice and interests, stated in the questionnaires, revealed a general interest of the students in the **living conditions in other countries**. They wanted to know: 'how children live there'; 'how people earn their living'; 'how many people don't have access to drinking water'; 'why people in Africa have severe problems curing diseases'. Their interest was caught by observations such as that 'some people are ready to fight and are not afraid of it', etc. **Only three** students explained their choice by **comparing living conditions elsewhere to life in our society**, e.g., 'the differences compared to our normal nutrition', and one student indicated his interest in the fact 'that the Western world is destroying the virgin forests of Africa'.

On the basis of all answers given to the questions and as an upshot from the discussions in the student focus groups (SFG) and the focus group (FG), the following features can be said to distinguish the students' interests (see Table 2).

Table 2: Features of interesting issues

	Features of interesting issues	Explanation
1.	The issues are of vital significance for people (basic needs)	See statements above
2.	They are linked to students' everyday life experiences	The majority of students eventually chose topics close to their life: family, diseases, nutrition, and waste
3.	They are of current interest and present in the media	The focus group assumed that this is one of the reasons why 11 students chose rainforest, which is very present in the media through TV documentaries and advertisements of the beer company Krombacher (according to which, one can save the rainforest by buying their beer!)
4.	Issues chosen for group work were influenced by group dynamics and relationships among the students	Figure 3 reflects this shift of priorities. Students explained it with the wish to work together with their friends
5.	Boys and girls differed clearly in their priorities (Figure 4)	The documents show no clear explanation of this phenomenon, because the research team missed the chance to explore it – chance for future studies!

Features 2 and 3 might not surprise teachers and researchers, as they reflect a common consensus that learning works best when it is close to life and relates to current events and developments. Feature 1 is remarkable, as the students themselves claimed their interest in living conditions in other countries. In some statements they expressed their empathy for people who are deprived of basic human rights and basic needs. Here we are at the core of DE. However, in the SFG, some students stated that 'they would not have done it at home', showing the importance of confronting young people with these issues within the formal education system.

Potential issues for the future in the eyes of students were:

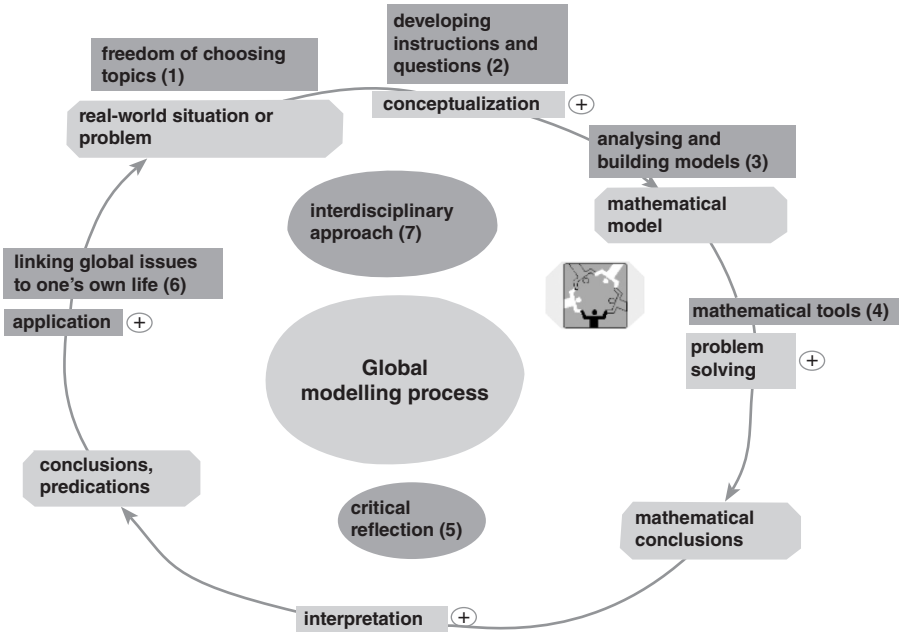
- all issues chosen in the introductory lesson, especially child labour
- living conditions in other countries
- situation and development of one country in detail.

Findings with regard to the second sub-question: What do teachers and students think are favourable conditions for a fruitful learning process in a modelling project focusing on global issues?

The learning process of the whole class was regarded as a joint modelling process.

The issues (see Figure 5) were identified as being critical in this process:

Figure 5: Critical issues related to the modelling process (derived from Figure 1)



In the following, these issues will be described in detail and used as a basis for defining a set of conditions favourable for learning in ME.

Freedom of choosing topics (1)

In all SFGs, all participants agreed that the freedom of choosing their own topics was a vital and appreciated element. This is illustrated by the following quotations: 'We could choose from many different topics and could have a closer look at them.' 'We didn't choose a group just to team up with certain classmates, but also because of the topic.' Their freedom of choice enabled the students to set their own priorities according to their interests. This resulted in a more motivating learning atmosphere, as one student expressed in reply to the question about the process of finding the specific questions: 'I made sure that I chose what I like.' Seven students out of 20 said the method to find topics of interest was 'super', 12 found it 'quite OK' and one was 'not sure.'[10] This was very positive feedback on the participatory learning approach.

10 Only 20 students out of 31 answered the questionnaire due to absence at the end of the session, participation in other courses, or sickness.

Developing instructions and questions (2)

The next step in the modelling process after the choice of issues was conceptualization. At this stage the researchers had to develop individual instructions for each group to provide guiding ideas and sub-questions to their topics and questions. The challenge was to reduce the complexity of the topics, find internet sites comprehensible to the students, and include sufficient data that were up to date. Students' comments on the instructions in the SFG were diverse: 'useful data, good relation between original question and sub-questions on instruction sheets', 'sub-questions too difficult', 'good hints and links', 'difficult: Links in English'. Hence the FG reflected this part of the process in detail. Lessons learned here were as follows:

1. For students in grade 8 with little or no experience in modelling, the instructions should be as concrete as possible. A typical student's question exploring data was observed by the mathematics teacher: 'We have 40 countries here, what should I take now?'
2. The instructions did not always provide readily accessible material for background knowledge.
3. English links should be avoided as much as possible. This is a real challenge when working on global issues.

Despite all these deficits, students' general feedback on the guiding questions was that they were helpful or even indispensable. However, developing the question was also very time-consuming and could only be accomplished by the external team.

To overcome this time problem, several alternatives were considered:

- cooperation with NGO working in the area of DE, as done here
- reduction of students' range of choice (an ambiguous alternative considering the insight of the first sub-question)
- developing routine in preparing the instructions.

Analysing and building models (3)

The FG had a long conversation as to whether the students were really modelling or just gaining 'GES knowledge with numbers' as the mathematics teacher put it. A detailed qualitative analysis of the posters showed that all the mathematical competencies – mathematical argumentation; problem solving; modelling; using mathematical forms of representation; using symbolic, formal and technical language and operations; and communication – had been applied by the students. On looking more closely at how students had to develop or use their existing competency in modelling, it was found that the groups either found diagrams and graphs on the internet (existing models) and tried to analyse them, or created

their own models. All groups recognized that the situations and questions had mathematical aspects and represented these by mathematical means (lowest level of performance: reproduction).

Using mathematical tools (4)

Students reflected on their use of mathematical tools in the project. They stated among other things that they had developed a better understanding of the size of numbers and learned to work out a line of best fit. A second suggestion brought up by the students was to provide internet links focusing on mathematics that could be used to look up or acquire mathematical skills. In this way time could be saved, which could be used for deeper reflection on the meaning and interpretation of diagrams and calculations.

Critical reflection and interpretation (5)

One of the competencies in the GDE Framework and an essential part of critical mathematical modelling, as discussed in section 2, is critical reflection on the issues being explored. Notes of participant observers and discussions in the FG showed that the topics dealt with offered great potential for critical reflection. The students were surprised by a graph that showed the relationship between the slum population, expressed as a percentage of urban population (Y), and the percentage of the population with a consumption below $1 per day (X) in Ghana between 1990 and 2001. Between 1992 and 2001, Y decreases, whereas X increases. The students would have expected the opposite. Why is the slum population decreasing and poverty increasing at the same time? Even with the help of the teacher they could not find out whether there is a causal relationship between the two quantities, and if so, why they correlate in this way. This illustrates the urgent need to complement mathematical exploration of phenomena with additional information that might not be available on the internet. One way to fill this gap would be to contact and interview experts from the Global South.

Linking global issues to one's own life (6)

Throughout the process teachers encouraged the students to search for links between the topics they were working on and life in Germany, including their own local context. Teachers tried to initiate thinking processes that might contribute to students' competency of 'being able to play an active role in society at a local, national, and international level.' In sequence 3.2 students had been asked to 'comment on links between the content on the posters and your everyday life.' This Post-it collection holds a great potential for discussing global–local interdependencies, which could only be explored to a small degree within the course of the project. Looking for signs of mathematical thinking, 24 out of 90 statements referred to numerical proportions

or quantities, e.g., 'Our death rate is lower because we have better medical services'. This is no proof, but it adds weight to the statement of reflection group D that drawing diagrams helped the students to understand causal relationships and differences.

Interdisciplinary approach (7)

In the SFG students said that the combination of GES and mathematics was 'cool'; they would appreciate interdisciplinary projects in the future and suggested integrating biology, chemistry, etc., but not English and French.[11] And they explained 'what was important for us was that we recognized causal relationships and differences, that everything is somehow interconnected'.

In Table 3 favourable conditions were derived from the findings (1) to (7) above:

Table 3: Favourable learning conditions

Critical issues	Favourable conditions
1. Freedom of choosing topics	**Learners choose their issues**. They can be interpreted creatively to accommodate topics and competencies described in the syllabi of Baden-Württemberg. 'Mathematics can be found everywhere' as outlined in section 2, as can links between the global and local level in societal issues of any kind
2. Developing instructions and questions	**Creating own material**[12] is a real challenge, but it is necessary for the conceptualization stage of modelling, avoiding the deficits mentioned above. This work can be shared by cooperating with an NGO in the field of DE
3. Analysing and building models	The learning process can benefit from **the wealth of interesting questions**, which can be explored by learners in groups, while in the process acquiring mathematical competencies, especially competency in modelling, e.g., analysing existing models or creating models themselves
4. Using mathematical tools	It is desirable to **include refresher courses** in the use of mathematical tools and especially the use of Excel
5. Critical reflection and interpretation	**Critically reflecting on and interpreting mathematical** models in the required depth might be difficult or impossible due to the complex nature of global issues. **Interviewing experts**, e.g., people from other countries living in Germany, might fill the gap
6. Linking global issues to one's own life	It is vital to encourage students throughout the process to search for links between the chosen issues and their own life. **Sufficient time** has to be provided for a **joint reflection** about these links at the end of the process to encourage them to think about our role in a global society
7. Interdisciplinary approach	**Teaching in a team** of a mathematics teacher and a GES teacher is highly recommended as a means of combining their knowledge and competencies in the field of ME and DE/GE

11 The researchers could not find out why students wanted foreign languages to be left out.
12 The internet platform BLIKK (www.blikk.it/angebote/modellmathe/sitemap.htm) might be an option.

5. Conclusions and recommendations for practice, policy and research

In section 2 an ideal global modelling process was described, showing how competency in mathematical modelling can be interlinked with global skills and competencies. This formed the theoretical basis for the main research question: *'How can the acquisition of mathematical competencies, especially competency in "mathematical modelling", encourage students (grade 8, age 14–15 years) in secondary schools in Germany to think about their role in a global society?'*

The detailed findings in the previous section were reflected on as an entity and condensed in order to gain an overall picture, describe main outcomes, and derive broader insights.

(a) The whole learning process, linking the educational worlds of ME and DE, has proven to be a very fruitful interdisciplinary approach (see above (7)). Acquiring mathematical competencies, especially competency in 'mathematical modelling', did encourage students to think about their role in a global society. In addition, students appreciated the learning atmosphere: 'Learning is easier for us with this method, we like it more and we learn more. It is more fun than "normal" lessons.' The whole project showed the added value of DE approaches in ME and vice versa.

(b) ME can be enriched by elements of DE (learning approaches, expertise): in DE there is a strong emphasis on a participatory approach, which takes the learners' wants and needs as a starting point of any learning process. Freedom of choice – allowing students to define their own topics close to their life (see Table 2) – is certainly a key element, which can contribute to the positive learning atmosphere, and eventually to the success of similar learning arrangements. This is supported by Pratt (2012), who suggests that real-world examples can demonstrate a sense of purpose to the subject of mathematics. Competencies and skills developed in DE (see section 2) correspond and complement the competencies of the modelling cycle. Figure 1 provides an ideal global modelling cycle, which can be used in future modelling projects in schools.

(c) The competency 'critical reflection and formation of opinions' (GDE Framework, BMZ/KMK, 2007), identified as a critical issue in the study, is vital for creating models or interpreting given models. Greer and Verschaffel (2007, in: Blum *et al.,* 2007: 223–4) refer to Jablonka (2003) in saying that the use of modelling for social situations has to '… be qualified by consideration of the diversity of people's lives, their practices, experiences, goals – in general culture.' (*ibid.*: 222–3). One important outcome of the study is the insight

that external expertise from NGOs in the field of DE can provide additional information, media, personal experience, and different perspectives of other cultural contexts to support critical reflection and interpretation of data gained in the modelling process (see above (5)). Facilitating critical thinking and mathematical modelling in one and the same project put high demands on the teachers.

(d) DE can be enriched by elements of ME: the project has shown that global modelling processes can help students to explore, understand, and interpret causal relationships and differences of global phenomena. The last step of the modelling process is the translation of the mathematical results back into the real world and the testing of their usefulness. At this stage the project had produced a wealth of statements on Post-its, which hold a great potential to discuss possibilities to act for a more just and sustainable world.

(e) As it was suggested by the mathematics teacher who was developing a teachers' guide on global modelling processes, describing how to support students in their learning, how to develop routine in preparing instructions on the basis of freely chosen topics by the students, and how to cooperate with external experts might be a joint future project of the 'ME and DE enterprise'.

(f) Schools and teachers should be encouraged to carry out similar interdisciplinary projects in cooperation with NGOs. As the projects have shown the importance of self-organized learning approaches, case studies carried out by students over a longer period of time might be appropriate. Educational reforms should provide framework conditions that promote interdisciplinary teaching and learning at the intersection of mathematics and other subjects relevant for DE and the cooperation with external partners.

(g) The potential that lies in rethinking DE and ME together on the basis of their common roots in critical pedagogy was discussed in section 2. In this study the focus was on mathematical modelling – a field of study holding great potential to be further researched in broader and deeper approaches. In addition, ethnomathematics and critical mathematical literacy open up a wide range of opportunities for future research.

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