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► **To cite this version:**

Gero Stoffels. Authentic-STEM: Opening long-term domains of experience for fostering students' and mentors' self-efficacy through mathematics. Thirteenth Congress of the European Society for Research in Mathematics Education (CERME13), Alfréd Rényi Institute of Mathematics; Eötvös Loránd University of Budapest, Jul 2023, Budapest, Hungary. hal-04420539

HAL Id: hal-04420539

<https://hal.science/hal-04420539v1>

Submitted on 26 Jan 2024

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Authentic-STEM: Opening long-term domains of experience for fostering students' and mentors' self-efficacy through mathematics

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Authentic-STEM is a project in which various stakeholders in STEM education and STEM career orientation from schools, universities, businesses, politics, and society work together to create a space for young people to experience self-efficacy in mathematics. This is achieved through long-term problem solving of real problems containing mathematics from businesses as well as contact with their employees moderated by mentors. These mentors are in focus of this contribution. Therefore, after describing the context of the project and problematizing suitable mentoring, a theoretical framework is developed that accounts for the complexity of this problem-solving context. The theoretical framework is then applied on artifacts from different cycles of the Authentic-STEM project. Finally, the paper concludes with an outlook on additional research questions for further development of the mentors' training and supervision for their and students' self-efficacy experience.

Keywords: Authentic learning, beliefs, career awareness, self-efficacy, STEM.

Context & issue: adequate mentoring for real mathematical STEM problems

Blum and Niss (1991, p. 38) distinguish between applied and purely mathematical problem solving, whose essential elements of their contents and structures are very similar but differ with respect to normative aspects of mathematics education. The article is especially interesting because it provides a very helpful connection between problem solving and modeling. Namely, "in other words, the problem solving process may require going around the loop *several* times." (Blum & Niss, 1991, p. 39). That is, in this original meaning of modeling, it is embedded in a concrete—in the best case real—problem solving process in which mathematics contributes to solving the problem. Various studies showed the benefits of such long-term engagement with a problem. It is an important mathematical skill and has accordingly found its way into various current educational concepts, such as the 21st Century Skills (Maaß et al., 2019; Bayazit & Ubuz, 2013).

The goal of the Authentic-STEM project is stimulating such long-term problem-solving processes. In this project young people (between 13 and 17 years of age) apply and enhance their problem solving skills to strengthen their self-efficacy through mathematical activity. During the whole problem solving process they are accompanied by specially trained mentors with a broad competence field. For this purpose, experience spaces are created in which international solver teams of 2-4 German and the same number of American students can work on real problems from companies over a longer period (approx. 3-4 months). This project was started based on the good experiences in the national predecessor project MINT-Pro²Digi (Stoffels & Holten, 2022), in which 20 companies were connected with 75 young people through 27 real problems. Authentic-STEM was then started in a pilot format in spring 2023, whereby the basic ideas of MINT-Pro²Digi were extended to include international collaboration between the young people. In the pilot 2 companies were connected with a total of 33 students through 3 problems.

From MINT-Pro²Digi and the pilot of Authentic-STEM three aspects have emerged as central for a successful implementation of the program:

- *the perceptible "authenticity" of the problem* (Vos, 2011), which was manifested over the longer period through regular exchange with business representatives;
- *the group size per country of the solver teams* with more than one student, so that they can exchange information, and no more than four students, so that teamwork is possible without major organizational effort (Hoegl, 2005);
- *mentoring the solver teams*, which means allowing students to work freely, providing support in the use of (digital) tools and collaboration solutions, and at the same time playing a moderating role between the different stakeholders, especially schools and businesses.

This paper focuses on the third aspect, the mentoring, as a key moment for making the self-efficacy experience of the participants but also the mentors possible. It is already well known that there are challenges working on applied problems for students but also teachers (Blum & Borromeo Ferri, 2009). To discuss the self-efficacy expectations of students as well as teachers the following paradigmatic problem from Authentic-STEM as well as students' and pre-service teachers' dealing with this problem is described.

Problem

Currently all shower shelves are manufactured in Germany and shipped to Plattsburgh, NY. The packaging process for shipment is very labor intensive and could be optimized regarding reduction of waste and working time. Due to shipping costs on the rise, space constraints, sales increasing, quality defects due to packaging and handling, and potential for automation of the packaging process; Schluter® Systems is searching for an improved, sustainable solution to package and ship material from Germany and their vendors to Plattsburgh while maintaining the quality expectation driven by the customers.

- Improve sustainability of packaging solution [+replacement for foam]
- Maintain quality expectations by customers (reduce damage caused by shipping)
- Prepare for possibility of automation for final packaging
- Improve ease of use/reduction wasted movement the current configuration causes on the operation and logistics

Figure 1: Description of the “Shower Shelves” problem by the company Schluter® Systems

How pre-service teachers deal with such problems is to be shown by a concrete example from a seminar in which elements of a possible mentoring training were tested. The assignment that led to the pre-service teachers' slide in Figure 2 was that the group of three students should adopt the authentic problem of Schluter® Systems for mathematics class. The slide contains two important aspects, which point to beliefs about mathematics teaching and mathematics education, besides the problematic modelling due to the missing edges of the shower shelf as well as the awkward modelling due to the choice of height for determining the area. Firstly, from the pre-service teachers' standpoint a mathematics educational preparation of the problem means that the problem solving process of the students is simplified by explicitly providing a model. Secondly, the explicit verbal justification for the juxtaposition of the photo of the shower shelf and the sketch of a "general" triangle with the corresponding formula shows, that the integration of such problems in mathematics lessons only “makes sense”, if a corresponding juxtaposition is given by the teacher.

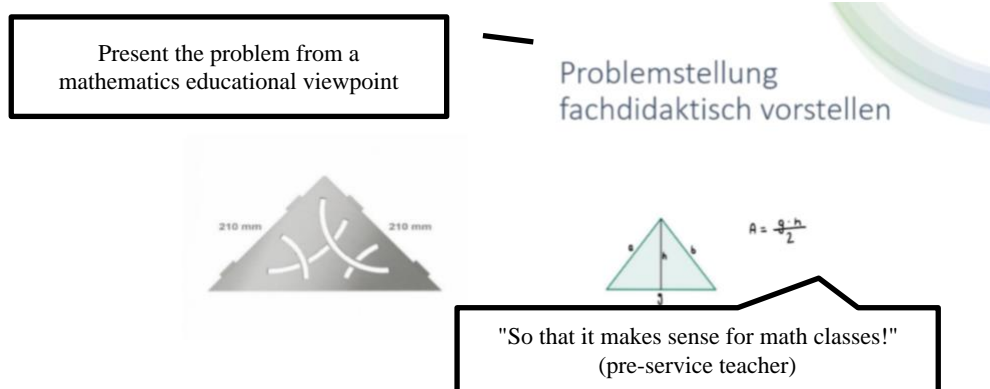


Figure 2: Idea from a team of pre-service teachers adapting the problem for the classroom

This reveals a fundamental scepticism on the part of pre-service teachers regarding students' self-efficacy. The following theoretical model shows why self-efficacy is only possible in appropriate experience domains, which necessitates mentoring with an optimistic view of students' self-efficacy.

Theoretical background: self-efficacy needs suitable domains of experience

In problem solving, metacognitive processes as well as different beliefs of the problem solver play a crucial role in addition to resources and knowledge about mathematics (Schoenfeld, 1985). Another important factor for successful problem solving is self-efficacy, that is, a "belief in one's capabilities to organize and execute the courses of action required to attain designated types of performances" (Bandura, 1997, p. 94). These are beliefs that focus precisely on metacognition, that is using appropriate heuristics or control one's own problem solving processes. How to promote such self-efficacy experiences for students, but also for teachers? According to this definition of self-efficacy as reflective beliefs, self-efficacy also depends on one's own perceived self-efficacy (Bandura, 1993).

Still a question in research on beliefs is in which way one can determine beliefs of individuals. To answer this question, methods of quantitative research, e.g., factor analyses (Grigutsch et al., 1998) or qualitative methods like image analyses (Rolka & Halverscheid, 2011) are used. As with other mathematics educational concepts, the applicability of the different methods depends heavily on the definition of the concept of beliefs. Regarding self-efficacy, the particular challenge is, that these are beliefs, or belief systems, about a person him/herself, so that persons must perceive themselves as actively acting. To reflect this in the definition, one possibility is to make the attribution of beliefs to a certain extent dependent on the person who makes this attribution. For example, Grigutsch et al. (1998) claim that their model of different views on mathematics, e.g., the formal view or schematic view, is dependent on their own perspectives as researchers and mathematics teacher educators. One possible definition that achieves this is by tracing the concept of beliefs back to the idea of domains of subjective experience (DSE): "Beliefs are identified by an observer indexing equivalence classes of DSE of the observed subject with respect to selected specific elements of the DSE" (Stoffels, 2020, p. 171). Going back to the concept of self-efficacy. In this case the observer and subject are the same, which is also relevant for the reflection of one's own beliefs in various cases (Stoffels, 2020). In the discussion of the example (Figure 2), the pre-service teachers' views indicate that they have activated DSE in this situation that assigns no, or only weak, self-efficacy to students. Further questions are

how and in what situation DSE are developed to promote self-efficacy, which requires a more detailed discussion of the concept of DSE (Bauersfeld, 1983).

Bauersfeld (1983, p. 9) himself understands DSE as a model for mathematical learning based on the "particularity of experiences contained in disparate domains of knowledge". In this context, besides knowledge, he also points to other specific elements (e.g., emotions, identity) that become relevant due to the discussed rather broad definition of self-efficacy according to Bandura (1997) and the totality of experience (Bauersfeld, 1983, p. 28). The self-efficacy of a subject then means that the subject has DSE in which he/she has become self-efficacious, or in which he/she has experienced his/her own action as self-efficacious, e.g. related to knowledge he/she has been able to answer a question correctly, related to motor skills he/she is able to perform an enactive experiment, or related to mathematical habitus he/she sees himself/herself as a productive member of a community in which "mathematical action is taken". Even in classical examples of research on DSE, where non-fitting DSE to a teaching-learning situation are often discussed, the important question is, in which ways experience domains can be designed and investigated in terms of their conditions of success in which students and teachers develop desired DSE (Stoffels, 2020; vom Hofe, 1992).

Empirical study: analysis of experience domains fostering perceived self-efficacy

A question that arises from the theoretical discussion is to what extent authentic long-term problem solving in the setting of Authentic-STEM offers experience domains for perceived self-efficacy of students but also mentors. This will be discussed based on concrete data from the pilot 2022, Spring 2023 and the mentor training.

Students experience self-efficacy in the long term

Authentic-STEM follows a four-phase concept. The cover letter of the students is part of the preparation phase. A female participant of the Authentic-STEM program in Spring 2023 gives following statement regarding her expectations about the program in her application letter. The topic was "why you want to become part of the project Authentic-STEM".

The Authentic STEM program would allow me to experience what it is like to solve concrete problems that employees in a company face, which you don't get to experience during school lessons. Not only would this help build problem-solving and critical thinking skills in the subjects I am most interested in, but also teamwork and leadership skills I consider crucial in life.

The following kick-off event ensures that the authenticity of the problem can be perceived by the participating students through contact between solver teams and business representatives. This is followed by long-term problem solving (3-4 months) in the solver teams with regular contact to the companies, before the students swap roles with the companies in the "Forum of Innovation" and present their solution processes.

Overall, this opens a rich experience domain in which students can develop their self-efficacy as a belief about themselves, which becomes explicit in the sessions (113 participants, multiple case study research) and follow-up interviews (10 participants, qualitative content analysis). This richness can be illustrated by three aspects based on the data:

1. *The Forming Phase of Solver Teams* (Egolf & Chester, 2013): In the first three weeks students have the self-efficacy experience of being allowed to formulate their own ideas, having them taken seriously, and being relevant to the progress of the project. Many students are often insecure during this phase because their school experience rarely provides them with such spaces, also for organizational reasons (cf. quote from the beginning of this paragraph).
2. *The experience that their ideas have real consequences*: One problem of the pilot involved automatization of an assembly line that was previously done manually by workers. Not only was the solver team's solution so good that their proposed solution was implemented by the business, but as the students themselves became convinced of the quality of their own idea during the cycle, they asked themselves and the business what would happen to the workers who had previously worked manually—in other words, an ethical issue. The business was happy to tell them, that the workers would be trained to become operators of the new machine.
3. *The experience of applying their mathematical skills, being able to explain their ideas well, and having adults and companies listen to them*: During one session a discussion came up naturally, about whether, for example, it is better to use trigonometric functions or the Pythagorean theorem to design a component. Mathematical considerations are also found in the presentations during the “Forum of Innovation” and are enhanced by considerations based on other STEM disciplines, for example sustainability. This is shown in Figure 3. Here, mathematical concepts appear explicitly, such as measures or different views. The tessellation appears only implicitly.

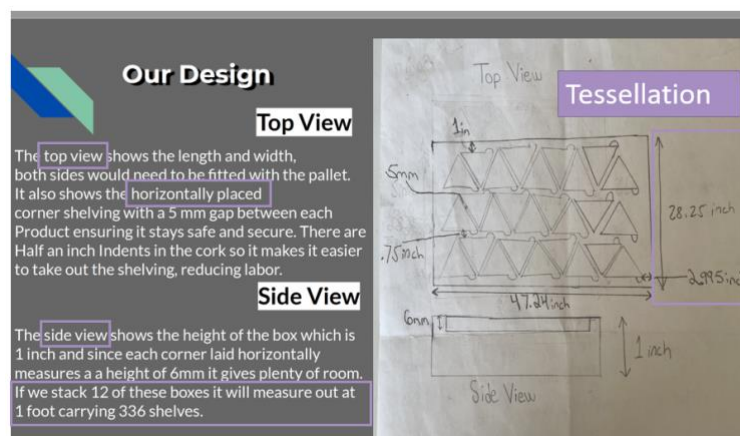


Figure 3: Middle school students' solution to the problem (mathematics highlighted)

Further interesting questions are to what extent the different aspects belong together and how the DSE that are built up through the self-efficacy experience are interconnected. In the upcoming cycles of Authentic-STEM we hope to gain deeper insights, especially into questions of "Mathematikhaltigkeit", which roughly means mathematicality of authentic-problems.

Perceived self-efficacy in the context of beliefs about mathematics teaching

Mentoring (Sundli, 2007) is the key to a successful implementation of Authentic-STEM. Besides questions which competencies from the areas of problem-solving, problem-solving noticing, dealing with digital tools and collaboration tools, overcoming the shyness of contact with related disciplines (usually STEM), communication, etc., beliefs about how mathematics is learned, how self-efficacy

is attributed to students and adolescents (Figure 2) but also to oneself are highly relevant. Accordingly, in a mathematics educational seminar in the winter semester 2022/2023, various modules were tried out addressing different areas of competence of mentoring in the project, but also for standard mathematics teaching. In this seminar 18 secondary pre-service teachers participated. This mentor training was documented with the help of digital learning diaries which were analyzed using qualitative content analysis embedded in a single case study.

At the end of the semester, the participating pre-service teachers were asked to rate the seminar topics covered according to their importance from their personal view. The results of this survey can be seen in Table 1. Since students named different topics, the one they personally considered most important was given the highest score (in reverse to the actual order). This analysis shows that for the students the concrete problem solving of authentic problems as well as their mathematics educational analysis were highly relevant. It is interesting to see that the students decide very heterogeneously what they consider to be particularly important. With respect to the visit of companies, differences probably occur because not all students were able to visit the business.

Table 1: Participants personal ranking of the mentor training modules from particularly important (highest number in column) to less important (=1)

Student	Σ	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
problem solving	48	6	1			7	2	6	6	5	2	4			1	8
problem solving noticing (using process models)	40	4	2	3		5	3		4	4		5			3	7
digital learning environment	36	3	5	2		6	5	1	2		1				5	6
learning diaries	35	1	4		2	2	1	5		2		1	2	3	7	5
business visit	31	5	3	4	4	3							4	4		4
Transcribing	30	2		1	3	4		3	5		3	3		1	4	1
project work using learning platforms	19						4	2	3				1		6	3
Communication	14					1		4	1	1			3		2	2
preparation of a problem	7									3		2		2		
presentation of the Authentic-STEM project	1				1											

A concrete example of a learning diary entry is given in the following entry from participant O (marked grey in Table 1).

Rank the topics of the mentor training from important to unimportant and explain your ranking.

1. important > unimportant: problem solving > observing in mathematics lessons > planning a digital learning environment > learning diaries > business visit > learning platforms > communication > transcripts.

2. I felt that problem solving was the most important aspect, as this is an important life skill for me personally. Learning about the different problem solving processes was also a very important and interesting experience for me. [...]

In Spring 2023 the participating mentors were prepared virtual through a mentoring training (4 modules) based on the modules from the previously described seminar. This training is currently under evaluation. For the first time, mentoring supervision is now also taking place, in which challenges of the mentoring are discussed formatively in the sense of collegial case consultation, which might provide new impulses for the mentoring training and mathematics teacher education as a whole. At the same time, key moments for the mentors' own self-efficacy are also to be reflected

upon and made explicit by the mentors to document them and gain further insights on the mentors' self-efficacy and self-efficacy attribution. These learnings from the mentor training program are important for teacher education, since the cooperation with teachers from the participating schools who supervise the students on site showed, that there is always skepticism, that their students can participate productively in such an open format. This already starts with the question whether it is a good idea to select the students by an open application letter (cf. quote from the previous section). This concern usually subsides at the latest after the forming phase of the project, although there are clear differences between participating teachers from the U.S. and Germany regarding the openness of mathematical teaching and learning processes that need to be investigated further.

Summary and outlook

This article exemplifies the effect of authentic problems from businesses on both students and future teachers. Similar experiences were also gathered in similar problems from MINT-Pro²Digi in contexts of robotics, process optimization, prototyping, etc. It turns out that, after a forming phase in which students experience that they can make a real contribution by solving a problem, they are able to develop problem solutions productively in experience domains as Authentic-STEM provides. In contrast, it has been shown for pre-service teachers that their conceptions of good mentoring are influenced by beliefs about successful mathematics teaching, especially their personal school experiences and/or the desire to simplify problems for students as much as possible, which has a hindering effect for students' own problem solving. Regarding the diverse and necessary competencies of mentors in dealing with real mathematics-related problems, observing problem solving processes, dealing with digital tools and collaboration tools, but also moderating various stakeholders of such a project, a heterogeneous spectrum emerges regarding personal interests and the assessment of the importance of the various fields of competence.

In the current Spring 2023 cycle, the larger cohort size (ca. 80 participating students) and an associated greater diversity of the different problems, might provide deeper insights into the participants' own self-efficacy expectations, but also self-efficacy attributions and their interconnectedness. In addition to the challenges of working across disciplines in STEM, insights into cross-cultural teamwork will be explored in more detail in future cycles.

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