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# Problem-based learning in STEM: Facilitating Diversity and Change in Pre-college Engineering Education through Online Collaborative Teacher Communities in virtual STEMlabs (Work in Progress) (Diversity)

## Svend Hauekrog Christiansen (Ph.D. Fellow)

Ph.D. Fellow at Aalborg University in cross-institutional collaboration in engineering in higher education. Prior practical experience as a research assistant working with STEM and Problem-based Learning. In addition, I have my master's degree in Techno-Anthropology, providing me with theoretical and practical socio-technical expertise.

## Lykke Brogaard Bertel

Associate professor in emerging technologies and problem-based learning in science and engineering education

## Bettina Dahl

Associate professor, Aalborg Centre for Problem Based Learning in Engineering, Science and Sustainability under the auspices of UNESCO, Aalborg University, Denmark. Full professor, Department of Mathematics (math education), University of Bergen, Norway. Full name: Bettina Dahl Søndergaard/Soendergaard.

# Problem-based learning in STEM: Facilitating Diversity and Change in Pre-college Engineering Education through Online Collaborative Teacher Communities in virtual STEMlabs (Work in Progress) (Diversity)

## Introduction

Due to increasing demands from industry and society, European and American education systems share the common goal to develop pre-college students' knowledge, skills, and competencies in the fields of Science, Technology, Engineering, and Mathematics (STEM) [1], [2], [3]. However, contemporary research depicts conceptual differences in the definitions of STEM teaching across engineering-related educations and highlights the need for a shared understanding of what STEM educations should contain [4]. Even though businesses and governments are promoting STEM in the educational systems, new inquiries and recommendations are necessary to mitigate the expected lack of STEM graduates in the future and to increase diversity in engineering educations and professions [2], [3], [5], [6], [7].

One major challenge is a decrease in motivation for STEM disciplines among pre-college students and teachers [8], [9], and research indicates a decline in interest in STEM disciplines as early as ages 11 to 15, or $6^{th}$ to $8^{th}$ grade [10]. Another challenge is to ensure teachers feel competent and confident in designing, facilitating, and assessing qualities and effects of STEM-integrated teaching as well as incorporating new 'external' requirements (e.g., computational thinking, artificial intelligence, sustainability, interdisciplinarity) into their teaching practices [11]. There is a lack of clear guidelines or instructions regarding STEM-collaborative efforts across disciplinary and institutional boundaries in pre-college engineering education, and teachers are often left to individually construct teaching material that extends beyond their domain of professional knowledge [4], [12]. Thus, current knowledge within educational practices in K-12 STEM points towards a need for more opportunities for teachers and students to engage in 'long-term' projects and collaborative learning that challenge the traditional 'single silo' thinking and allow for knowledge-sharing across disciplinary and institutional boundaries [4], [9], [13]. Problem-based learning (PBL) is a student-centered approach to teaching and learning that offers students the possibility to engage in interdisciplinary and experiential learning. This pedagogical approach is increasingly integrated into educational contexts in both engineering education and pre-college engineering [14], [15]. Main features of PBL include working with real-life problems with an emphasis on self-directed and collaborative learning, which can lead to the transformation of students' perception of and approach to complex problem solving [16], [17]. Another common principle of PBL is exemplarity; meaning that problems and solutions resemble and serve as good examples of the students' future profession [17], [18], [19].

This paper presents the Danish research and development project LabSTEM North and explores PBL as a framework and approach for teachers across K-12 schools, pre-college engineering, and higher education to co-create STEM-integrated learning experiences and teaching material through collaborative and digitally supported STEMlabs. In the following, we present the reasoning behind the project, its organizational and methodological approach, as well as the first phases of establishing virtual STEMlabs in the Northern region of Denmark. We discuss preliminary findings, potentials, and challenges related to the ongoing development of regional collaborative learning communities for teachers across disciplinary and institutional boundaries to facilitate change and diversity in the local K-12 system and support pre-college

students' interest in engineering and STEM-related educations and career paths, in particular women and minorities.

## The LabSTEM North project

To identify crucial components needed for teachers to feel confident and competent in including new STEM elements into existing teaching practices, a deeper understanding of contemporary STEM teaching across the chain of education is needed. Thus, a three-year project has recently commenced with the collaboration of more than 80 teachers from K-12 schools, pre-college engineering, and higher education institutions in the Danish region of Northern Jutland – LabSTEM North (2021-2024) lead by Aalborg University [20]. LabSTEM North seeks to create *a framework for PBL-based and STEM-integrated teaching* to support interdisciplinary and cross-institutional development of educational designs applicable and adaptable to different educational contexts. The purpose is to create inspiring and engaging learning experiences and teaching material, hopefully translating into an increase in student motivation and aspiring STEM candidates. The northern region of Denmark faces particular challenges compared to the rest of the country when it comes to industry's need for STEM candidates in the future, thus it is essential to initiate local efforts to ensure diversity in STEM-educations and career paths and to improve retention in pre-college engineering and higher education STEM [21]. The LabSTEM North project is inspired by and collaborating with a similar effort in the southern region of Denmark, focusing on the integration of Mathematics in STEM-teaching through a *STEM laboratory model* [22], [23]. In LabSTEM North, the focus is STEM-integrated teaching, i.e., incorporating a minimum of two or more STEM "letters", and the STEM lab model is transformed into a *virtual* STEMlab model, providing flexible and free access to workshops, digital resources, and teaching materials.

What distinguishes the LabSTEM North project from other efforts to develop interest in STEM in K-12 and pre-college engineering, is its focus on PBL as a value-based foundation for developing integrated STEM-teaching on all levels of education, as well as the implementation of an online platform to support a collaborative community of practice in the region. Thus, LabSTEM North seeks to inform and contribute to an underrepresented research area and provide insight into how to develop and facilitate local and virtual teacher-communities to consolidate PBL-based and STEM-integrated teaching in practice with the purpose of facilitating motivation, inclusion, and interest in STEM educations and careers [24], [25]. By including both students, teachers, and management in the project, a link between learning goals, local professional practices, and student motivation in transitions between K-12, pre-college engineering, and higher education STEM is incorporated into the LabSTEM research design.

## Research design and methods

The research design and methodology in LabSTEM North is inspired by *Design-based research* (DBR). In DBR, contextual understandings and incorporation of multiple iterations of designs for change-making in collaboration with stakeholders are considered essential to support *a holistic process of transformation* based on and contributing to new theoretical knowledge [26]. In this sense, DBR has much in common with PBL as both approaches seek to establish domain-specific knowledge and discover complexities that guide the identification of problems, experiences, contextual factors, and relevant solutions [27]. Through an iterative process of intervention, experimentation, and adjustment of knowledge to and with practice, researchers and teachers in pre-college engineering and STEM education, collaboratively explore, develop and refine practice-based designs and theory [27].

The project is organized around five interconnected activities or phases, each incorporating different qualitative and participatory methods (see figure 1). Based on a preliminary case study on current and best practice within STEM-teaching (1), a theoretical framework for problem-based and STEM-integrated teaching is co-created, elaborated, and refined (2) in close connection with exploration and experimentation in practice (3). Alongside this iterative process, a conceptual model for virtual STEMlabs to support online collaborative learning communities, as well as online resources, are developed and tested (4) and all activities are continuously disseminated in relevant local, national, and international communities (5).

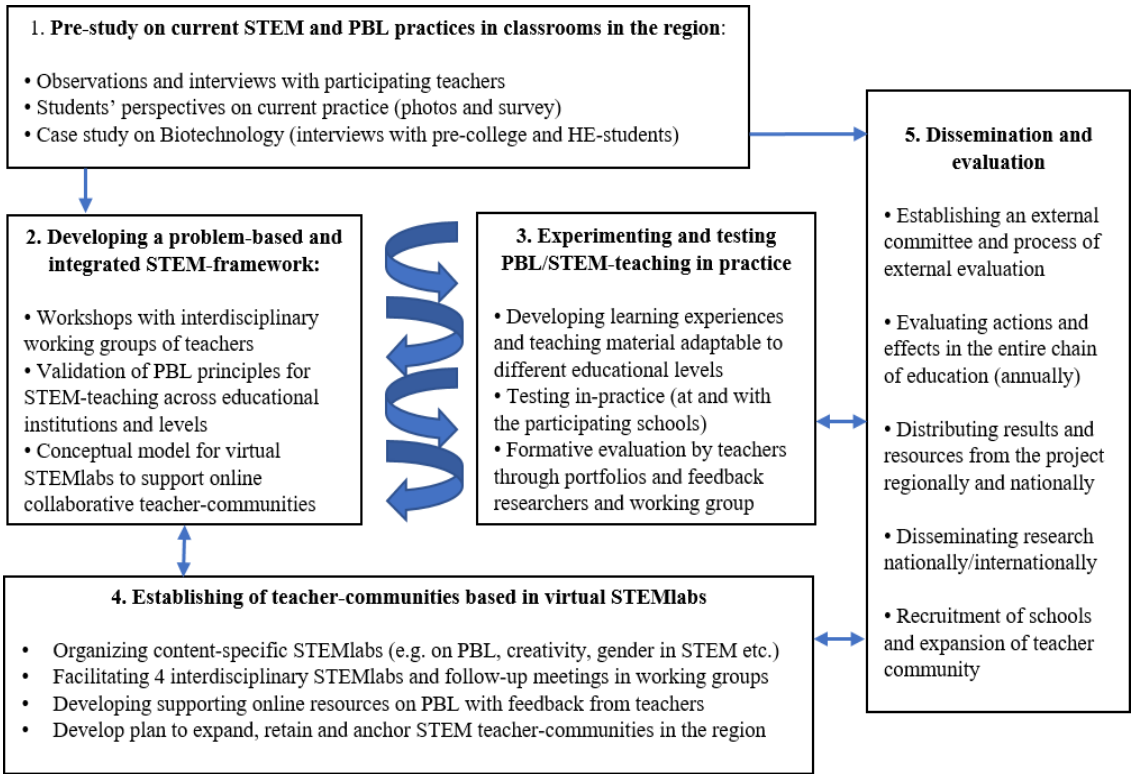


*Figure 1:The design-based research process in LabSTEM North*

As the project launched in March 2021, the first year has focused particularly on the pre-study of existing and best practices (activity 1 in figure 1) and on establishing and testing out virtual STEMlabs (activity 4) as well as on recruiting schools, pre-college engineering institutions and teachers to LabSTEM (activity 5). In early 2022, the iterative process of developing a problem-based and STEM-integrated teaching approach and testing it in practice has commenced (activities 2 and 3).

## Preliminary findings

As DBR allows for, and emphasizes the continuous reflection on and adapting to potentials, challenges, and critical issues in practice to improve theories, methods, designs, and practicing awareness and reflexiveness is crucial in all stages of proposing, preparing, facilitating and assessing research and educational designs. Thus, practical knowledge and collaborative reflection in the current early stages of the LabSTEM North project are used by both *researchers* and *teachers* to improve areas of current project processes. In the following we

will highlight two such areas: the creation of collaborative teacher communities across disciplinary and institutional boundaries; and facilitating online collaborative learning in virtual STEMlabs.

*Creating boundary-crossing collaborative teacher communities*

As the purpose of the STEMlab was to facilitate the collaboration between teachers from K-12 STEM, pre-college engineering, and higher education in developing educational designs across disciplinary and institutional boundaries, we have found that a common point of reference in PBL can help guide knowledge sharing and co-creation. However, the specific composition of disciplines in the STEMlabs might play a significant role in the focus of and extent to which the collaborative learning within the lab becomes problem oriented. Whereas all the (currently nine) STEMlabs (varying from two to 19 participating teachers) apply PBL in various forms regardless of whether the STEMlab is subject-specific (e.g., Math) or interdisciplinary (e.g., Technology), none of the current STEMlabs are defined by a *shared problem* (e.g., 'how to increase student interest in STEM through inquiry' or 'how to incorporate sustainability and SSI issues into STEM-subjects', etc.). On the one hand, sharing a common foundation in a discipline, subject, or field of expertise and being subject to the same curricula requirements, might increase identification with the learning community and help reduce potential barriers when working across institutional boundaries (e.g. misunderstands, varying levels of engagement, or dissimilar educational design criteria). On the other hand, it might result in a lack of explication of tacit knowledge or challenge the integrative approach to STEM needed to address complex problems in practice. Furthermore, in pre-college engineering and engineering education in general, the STEM-subjects are often intertwined in practice (e.g., math used as a tool in engineering), involving several or all STEM-subjects in complex problem-solving processes rather than the traditional 'silo-thinking' of STEM-disciplines. Thus, one could argue this too should be reflected in the composition of the STEMlabs as well as in the developed educational designs and teaching materials to encircle how these compositions support future students enrolling in engineering or other STEM-related educations.

*Facilitating online collaborative learning in virtual STEMlabs*

The virtual STEMlab model emphasizes the design and facilitation of online workshops for teachers across K-12 and pre-college engineering, to act as a catalyst for idea-generation and co-creation of PBL-oriented and STEM-integrated educational designs in the STEMlabs. Thus, this involves the process of determining which online platforms are suitable for facilitating productive collaboration. The transition to online platforms for facilitating collaboration has in similar contexts proven to be a potentially elaborate and fallible process, due to differences in individual preferences, prior technical skills, or level of motivation to operate on digital platforms [25]. In LabSTEM North, MS Teams was chosen as the online platform with specific channels for workshops, online material, and STEMlab virtual meetings. However, providing only an *online* space for teachers to interact and join forces as designers and practitioners of their respective disciplines has proven challenging. Having completed seven out of 15 planned workshops in 2021-2022, it has become apparent that the number of sign-ups from teachers is gradually decreasing, and that a rethinking of the use of the virtual space is necessary. Thus, the reasons and potential solutions for sustaining participation and motivation in the project were identified through informal conversations with teachers and management. The findings include confusion, when navigating the STEMlab platform (as an additional platform alongside the many other platforms teachers are required to participate in), short notice for schedule planners at the schools, and thus lack of time to participate in workshops. Furthermore, shifting

COVID-19 restrictions at the schools significantly increased the workload for teachers, which further added to this. This became an increasingly pressing issue, as some expressed discouragement and a decrease in confidence in integrating PBL and STEM perspectives in existing teaching practices. Related research shows that a lack of technical prerequisites and know-how can lead to demotivation or frustration in professional development [25], [26]. Thus, creating a space where experimentation and 'failing' is allowed and even encouraged, whether it be using digital technologies or experimenting with PBL and STEM-integrated teaching is vital in ensuring optimal conditions for both 'off-' and online collaborative teacher communities [27]. Furthermore, based upon feedback from teachers, it was decided to transition from fully online to a blended or hybrid STEMlab model consisting of both online and physical presence for the remainder of the project period, combining online resources and seminars with face-to-face workshops and on-site visits to participating schools, labs and educational institutions.

## Conclusion and next steps

Preliminary findings and reflections from the first steps of design-based research into the potential of online collaborative teacher communities in virtual STEMlabs to support diversity and change in pre-college engineering education and STEM teaching have enabled the LabSTEM North project to adapt to emerging issues, such as aligning participating teachers' perception on how future engineering students can be prepared for an increasingly more technological and complex world and adjusting to their expectations towards participating in STEMlabs.

A concrete argument for including teachers in the early design and development phases of new PBL-based and STEM-integrated educational designs is that the teachers gain confidence with problem-based and integrated/interdisciplinary approaches to learning by working problem-oriented themselves and 'engineering' their own STEM teaching practice, thus internalizing the learning designs and methods through exemplarity. Thus, the call for teachers to be able to provide learning experiences that resemble the complexity students will face as potential future engineers can be supported by a similar problem-based approach to the exchange of ideas, professional practices, and boundary-crossing educational development with teachers across K-12, pre-college engineering and higher education.

These preliminary findings will inform and further develop our approach to and practices in developing PBL-oriented and STEM-integrated learning experiences in the next phases of the LabSTEM project, particularly concerning the composition of future problem-oriented STEMlabs as well as in practicing physical, blended and hybrid models of facilitation in the labs. Furthermore, the exploration and experimentation with co-created educational designs in 2022 will initiate another iteration of exploration, reflection, and adjustment following the experiences and needs of participating teachers. An emphasis is placed on supportive tools, guiding principles and templates for teachers to plan and communicate their intentions and educational designs as well as on online resources to support specific subjects or interdisciplinary collaboration in LabSTEM and similar contexts. Finally, extensive empirical and contextual data will be collected through observations, interviews, and portfolios, and a framework for evaluating the effects of PBL and STEM-integrated approaches to teaching on student motivation, inclusion, and retention in K-12 STEM and pre-college engineering will be developed for further iterations of testing and refinement.

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