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Research article

Expanding the STEM integration model introducing the learning environment

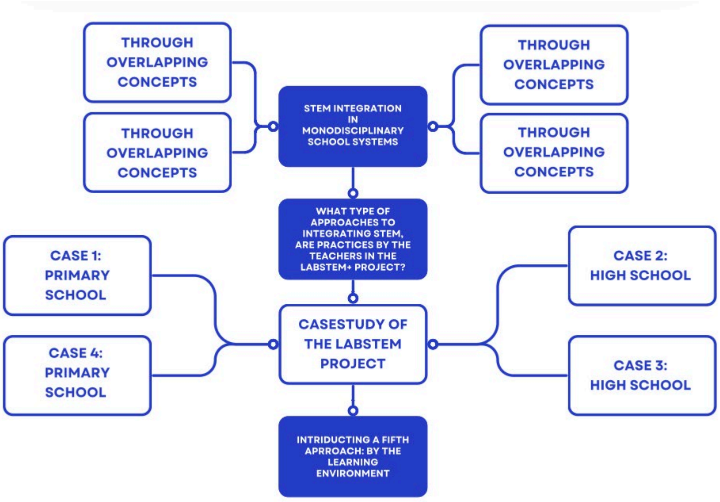
Maiken Westen Holm Svendsen, Dorte Moeskær Larsen and Connie Svabo

University of Southern Denmark, Denmark

Abstract: The increasing demand for a future-ready workforce, driven by rapid technological advancements, has positioned STEM (Science, Technology, Engineering, and Mathematics) education as a global priority. Despite its recognized importance, integrating STEM within traditionally monodisciplinary educational systems poses significant challenges. These include rigid curricula, subject compartmentalization, and institutional constraints that hinder interdisciplinary collaboration. This study aims to address these challenges by proposing an expansion of the existing STEM integration model developed by Seidelin and Larsen in 2021, which originally includes four approaches: content integration, overlapping methods integration, overlapping concepts integration, and context integration. The proposed expansion introduces a fifth element focused on the learning environment, recognizing the critical role that physical spaces, local contexts, and materials play in shaping integrated STEM education. The study draws on insights from the Danish LabSTEM+ project, where educators utilized what the project calls a laboratory model to explore the impact of the learning environment on STEM teaching. Methods included field observations, interviews, and the analysis of four case studies involving diverse educational contexts. The results demonstrate that the learning environment serves as a new way of integrating STEM. This addition of a fifth element to the integration model by Seidelin and Larsen offers a more comprehensive framework for STEM integration. The study concludes that the learning environment can be seen as a core component of developing integrated STEM teaching.

Keywords: STEM education, integration model, learning environment

Correspondence: mwhs@imada.sdu.dk



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1 Introduction

The urgency of cultivating a future-ready workforce has intensified in recent years, driven by the rapid advancement of technology and science. STEM education, an acronym for Science, Technology, Engineering, and Mathematics, has become a central focus globally as nations strive to equip students with the skills and competencies necessary to thrive in a technologically driven world (Bybee, 2018; Svabo et al., 2024). Introduced by the U.S. National Science Foundation in the 1990s (Sanders, 2009), STEM has evolved from a concept into a critical component of educational reform aimed at developing technical, digital, and mathematical competencies (Møller, 2022).

Despite the recognized importance of STEM education, its implementation faces considerable challenges, particularly within a traditionally monodisciplinary educational system (Hsu & Fang, 2019). The conventional structure of education, where subjects are taught in isolation, creates barriers to effective STEM integration. In integrated STEM teaching teachers are required to collaborate across disciplines to provide a cohesive STEM experience, a task that is complicated by the compartmentalized nature of the educational system, where subjects are thought separately, and only with small overlaps and integration. This structure limits opportunities for interdisciplinary collaboration and integration, as teachers are typically also trained and accustomed to teaching within their specific subject areas. Consequently, they may lack the pedagogical strategies and confidence needed to integrate content across different STEM disciplines effectively (Svabo et al., 2024). Additionally, there is often a lack of administrative support for STEM integration (Svabo et al., 2024). Logistical challenges, such as scheduling and resource allocation, further complicate STEM integration. Coordinating between different teachers to create joint projects or lessons requires significant planning and collaboration time, which is often scarce (Svabo et al., 2024).

Despite these challenges, teachers employ various approaches to integrate STEM into their practice, striving to create more cohesive and interdisciplinary learning experiences for their students. These approaches range from collaborative project-based learning to the development of interdisciplinary curricula, each aiming to bridge the gap between the traditionally separated subject areas (Larsen et al. 2022). One common approach is the use of project-based learning (PBL), where students engage in projects that require the application of knowledge and skills from multiple STEM disciplines (Bertel et al., 2023). For instance, a project might involve designing and building a model bridge, incorporating principles of engineering, physics, mathematics, and technology. This method encourages students to see the connections between different subjects and understand how they can be applied together to solve real-world problems. Another approach is the development of thematic units (Nur et. al., 2019), where teachers design a series of lessons around a central theme or concept that integrates content from different STEM areas. For example, a unit on renewable energy might include lessons on the science of solar and wind power, the mathematics of energy efficiency, and the engineering design of renewable energy systems. This thematic approach helps students make connections between subjects and understand the broader context of the content they are learning (Nur et. al., 2019).

With the aim of providing an overview of approaches to integrating STEM, Seidielin and Larsen (2021) conducted a literature review on methods of STEM integration. They argue: "*We contend that there are at least four different approaches to this integration: based on specific contexts/topics, on various methods/approaches, on cross-cutting concepts, or on one or more of the STEM disciplinary domains*." (own translation, Seidelin & Larsen, 2021). The framework addresses that STEM integration can be categorized into four main strategies: integration by method, integration by topic, integration by subject domain, and integration by crosscutting concept. This framework can be used as an instrument in guiding educators toward more effective STEM integration practices. The framework of Seidelin and Larsen (2021) was introduced as a conclusion of their work in the NOVO Nordic founded LabSTEM initiative project runed from 2020-2022, which aimed to support teachers in developing and implementing integrated STEM teaching. After the conclusion of the initial project, an extension was granted under the name LabSTEM+. This extended project forms the framework for this study.

1.1 Purpose and scope

In response to the integration challenges, this article aims to propose an expansion of the STEM integration model (Seidelin & Larsen; 2021) by arguing for a fifth approach to integrate STEM in activities. The main research question of the study is: What type of approaches to integrating STEM, are practices by the teachers in the LabSTEM+ project?

The study seeks to explore the various approaches to integrating STEM that are practiced by teachers within the LabSTEM+ project. By identifying and categorizing these approaches, the research aims to provide a comprehensive understanding of how STEM integration is implemented in real-world classroom and learning environment settings.

Through this examination, the study aims to contribute valuable insights to the field of STEM education by highlighting innovative and effective practices that can inform future educational initiatives and support the professional development of teachers. Furthermore, the research seeks to contextualize these practices within existing theoretical frameworks of STEM integration, evaluating their relevance and applicability in practice. By bridging the gap between theory and practice, the study aspires to advance both the understanding and implementation of STEM education in diverse educational settings.

The LabSTEM+ project provides empirical data, and the following sections will delve into the theoretical foundations of STEM integration, present detailed case studies from the LabSTEM+ project, and discuss the implications of incorporating the learning environment into the STEM integration model. This exploration aims to provide a comprehensive framework for advancing STEM education and addressing the challenges faced by educators in a traditionally structured system.

2 Theoretical framework – The STEM integration model

This section goes into the theoretical framework presented by Seidelin and Larsen (2021), specifically their *STEM Integration Model*, which is pivotal for understanding the seamless merging of STEM disciplines within educational contexts. By examining these four integration strategies, this section aims to demonstrate how educators can bridge disciplinary divides and create a more unified STEM curriculum, thereby enhancing student learning and engagement.

The integration of STEM in educational settings offers both opportunities and challenges for advancing interdisciplinary learning. Seidelin and Larsen's (2021) model provides a nuanced framework for this process, categorizing STEM integration into four distinct approaches: integration by method, by topic or context, by subject domain, and by crosscutting concept. Represented visually as a flower with four overlapping petals, this model serves as a guide for educators aiming to create a more cohesive and interdisciplinary learning experience. The overlap of the petals symbolizes that these approaches are not isolated but can complement and coexist with one another, as noted by Seidelin and Larsen (2021).

Integration by S-T-E-M Subject Domains: This approach involves using a core subject within STEM, such as engineering (E) or mathematics (M), as the foundation for integrating the other disciplines. Mathematical modeling has been highlighted in the literature as an effective framework for such integration (Doğan et al., 2019; Mass et al., 2019). Similarly, engineering has also been utilized as the central integrating subject (Nielsen et al., 2017; Guzey et al., 2016). While this method allows for the exploration of specific academic subjects through multiple disciplines, it can create an imbalance, with the core subject potentially overshadowing the others, relegating them to secondary roles. For example, consider a biology lesson focused on bird feeding habits. While biology provides the primary context, this subject can also be enriched by integrating statistics to analyze feeding patterns and technology to observe and record bird behavior. This interdisciplinary approach not only deepens understanding but also illustrates how different fields complement and enhance one another. Additionally, technology can be integrated by applying computer science concepts such as algorithms and data analysis to model real-world scenarios. For instance, students might use coding to create simulations that demonstrate mathematical concepts like probability or statistical distributions, or to design engineering models that optimize system efficiency. This method not only reinforces mathematical and engineering principles but also highlights technology as a powerful tool for exploring and integrating other STEM subjects.

Integration based on interdisciplinary topics or contexts: This approach utilizes complex contexts and topics to facilitate integration through functional means. For instance, environmental or energy-related topics can serve as the basis for combining different core areas (Nadelson & Seifert 2017). The chosen context or problem should be adaptable enough to incorporate various perspectives and robust enough to be understood across different academic frameworks (Klausen, 2011). Common STEM contexts might include career-related themes, energy resources, environmental quality, disaster management, health promotion, natural resources, and research and innovation (Bybee, 2018). This approach allows students to engage with real-world situations. For example, an energy resource project might involve studying the science behind renewable energy, using engineering principles to design energy-efficient systems, applying technology to monitor energy usage, and utilizing mathematical models to predict energy savings. Such interdisciplinary contexts encourage students to see the connections between different STEM fields and understand how they can work together to understand different interdisciplinary topics. Contexts for integration can be based on real-world scenarios (Larsen et al. 2022), which are often complex and require interdisciplinary approaches.

***Integration through different teaching methods*:** This approach facilitates the combination of disciplines through different methods such as inquiry-based teaching or problem-oriented approaches. Inquiry-based teaching emphasizes exploration and argumentation, often leading to interdisciplinary engagement driven by students' curiosity and ideas (Artigue & Blomhøj, 2013). Project-based learning involves students working collaboratively to address real-world problems, requiring them to integrate theories, methods, and tools from various disciplines based on the nature of the problem (Savery & Duffy, 2001). For example, in an inquiry-based project, students might investigate the impact of pollution on local ecosystems. This would involve scientific research to understand the pollutants and their effects, technological tools to measure pollution levels, engineering solutions to mitigate pollution, and mathematical models to analyze data and predict future impacts.

Integration based on crosscutting concepts: This approach focuses on interdisciplinary crosscutting concepts that span Science, Technology, Engineering, and Mathematics. Bybee (2018) identifies several crosscutting concepts, such as patterns, cause and effect, scale, proportion, and quantity, systems and models, energy systems, structure and function, and stability and change. These concepts enable students to connect knowledge from different core areas, forming a coherent scientific view of the world. For instance, the concept of cause and effect involves understanding mechanisms and explanations that can be tested across different contexts (Bybee, 2018). A lesson on this concept might involve studying the cause and effect relationships in climate change. Students could explore the scientific causes of climate change, use technology to model its effects, apply engineering to design solutions to mitigate its impacts, and use mathematics to analyze data and predict future trends.

Utilizing these four approaches makes STEM integration a dynamic and flexible process. This accommodates various educational goals and contexts while fostering a more cohesive and practical understanding of the interconnected nature of science, technology, engineering, and mathematics. It is important to note that these approaches often overlap. For instance, a problem-oriented approach can frequently be applied when working with a specific topic within a subject, or one might begin with a context-based problem that requires a problem-oriented approach to address the context-specific challenge. However, the way these areas overlap can vary across different educational activities and projects, highlighting the flexible and interconnected nature of STEM integration.

The four described approaches are particularly interesting and will be utilized as analytical tools in our development and research project focusing on the developed STEM activities. In the following section, this research project will be discussed in greater detail, along with an overview of the methodologies employed to assess the teachers approach for integrating STEM in LabSTEM+.

3 The LabSTEM+ project and methods

The LabSTEM+ project, funded by the Novo Nordisk Foundation, is a Danish initiative running from 2023 to 2025. The project brings together approximately 50 teachers from primary to secondary education. These teachers collaborate in 10 differnet "laboratories," where groups of 5-6 teachers work together to develop and share STEM programs with a focus on mathematics. In LabSTEM+ the Laboratory Model (Svabo et. al., 2024) was used as an innovative method, to workplace-based competence development of the school-teachers, by incorporating design principles and methodologies (Brown, 1992; Svabo & Shanks, 2014). The laboratory model is grounded in action research (Carr and Kemmis, 2005), and collaborative reflection, which empowers professionals to become active agents of change within their own practices. By engaging in iterative adjustments, educators and practitioners can develop real-world competencies that enhance their effectiveness in dynamic and evolving contexts (Svabo et al., 2024).

The teachers in the different laboratories work together with the researchers to discuss relevant issues and devise actionable strategies for improvement. A key component of this approach is collective reflection, which fosters shared learning and deeper insights (Svabo et al., 2024).

This article focuses on the first iteration of the LabSTEM+ project, involving four different laboratories that include two upper secondary schools with a total of 12 teachers and two primary schools also with a total of 12 teachers, comprising both mathematics teachers and teachers from other STEM disciplines. The LabSTEM+ design principles were introduced to these teachers, covering STEM teaching principles developed in the earlier LabSTEM project (2020-2022) and published by Svabo et al. (2024). The STEM principles emphasize that teaching should be oriented towards real-world applications, be participant-oriented, incorporate at least two of the four STEM disciplines, align with the respective educational level curricula and promote general STEM literacy (Larsen et al., 2024).

In this study, data was generated through an intensive fieldwork approach, involving a series of six researcher-visits to each of the four schools involved in the first iteration of the project. During these visits, comprehensive field notes were recorded in logbooks to document the processes and interactions observed in real-time. Additionally, in-depth group-interviews were conducted with the participating teachers, and these interviews were subsequently transcribed to ensure accuracy and facilitate detailed analysis. Video-observational data from the classrooms was gathered in between 4-10 lessons in each school to capture both the development and execution phases of the STEM educational interventions. This included close observation of the teachers' collaborative efforts in designing their instructional activities and observations of their actual teaching practices in the classroom. These observations were supplemented by video recordings of the teaching sessions, providing a rich, multifaceted dataset for analysis. The combination of these methods allows for a thorough understanding of both the planning processes and the practical implementation of the STEM activities in these diverse school settings. To ensure the reliability and validity of the qualitative data, multiple strategies were employed. For the interviews, a semi-structured format was used, allowing for consistent questioning across participants while providing flexibility to explore context-specific insights. The interview guides were designed based on prior research in the LabSTEM. For observational data, reliability was strengthened through triangulation within the research group. This included cross-referencing observations documented in field notes with video recordings and interview data to corroborate findings. Additionally, multiple researchers participated in the data analysis process to reduce bias and enhance inter-rater reliability. Regular discussions and reflective sessions among the research team further supported the consistency of coding and interpretation.

The selection of the four cases presented in the following section was primarily guided by the fact that, during the first year of the project, there were exactly four laboratories in operation. This aligns however well with the aim of capturing a diverse range of educational settings, as these four laboratories represent different variation in institutional contexts, student age groups, and teaching practices. Two high schools and two lower secondary schools were included to represent variation in institutional contexts, student age groups, and teaching practices. While the study does not aim for generalizability in the statistical sense, the diversity of the cases allows for analytical generalization (Yin, 2009), offering insights that can inform similar contexts and contribute to broader discussions on STEM education integration.

3.1 Case studies in the project

The four laboratories in the LabSTEM+ project are characterized here as four distinct cases, each of which will be individually described. These cases are first analyzed in relation to the theoretical framework of STEM integration approaches proposed by Seidelin and Larsen (2021). After the descriptions of the cases and the analyses, a table 1 has been constructed to provide an overview of the analysis.

Case 1: Primary School Laboratory

This laboratory took place in a public lower secondary school in Jutland, where six teachers specializing in mathematics and science collaborated to create a STEM module for 7th and 8th-grade students. The project centered on constructing race cars, culminating in a Grand Prix event to evaluate the best-performing car. The teachers were particularly inspired by the engineering component of STEM, adopting the engineering design process approach (Sillasen et al., 2017). This involved defining a problem, brainstorming solutions, planning and developing prototypes, testing and evaluating these prototypes, and iterating based on feedback.

The teachers' approach to integrating STEM in this case aligns with integration with a focus on method from the integration framework (Seidelin & Larsen, 2021). The use of the engineering design process as a structured yet flexible framework provided a method for organizing the students' work and integrating STEM disciplines in a cohesive way. By guiding students through iterative prototype development, the teachers fostered both critical thinking and practical skills. This approach emphasized how methodological frameworks, like the engineering design process, can serve as a unifying structure for interdisciplinary learning.

The concept of engineering is particularly intriguing in this context, as it also represents one of the letters in S-T-E-M. In this way, one could argue that integration has, in fact, occurred through one of the STEM subject domains. Here, the letter "E" effectively becomes the focal point around which the other letters in STEM revolve. This laboratory case also employs the context approach from the integration model by embedding the engineering design process within a real-world, meaningful scenario, the construction of race cars for a Grand Prix event. The context of designing, building, and testing cars provided students with a concrete and engaging challenge, connecting STEM disciplines through a shared, purposeful activity. This approach emphasized the relevance of STEM concepts by situating them within a context that mirrored authentic engineering practices, enhancing both motivation and understanding.

In conclusion, the integration in this case draws on three complementary approaches: integration with a focus on method, where the engineering design process structured interdisciplinary collaboration; integration through a STEM subject domain, with engineering serving as the central anchor for the activity; and context integration, by framing the learning experience in an authentic, real-world problem. Together, these approaches illustrate how STEM education can be cohesively organized to foster critical thinking, practical skills, and deeper engagement.

Case 2: STX Gymnasium

The second case is a (STX) gymnasium on Funen where seven teachers designed a STEM module with a strong emphasis on core academic content in each discipline. The teachers sought to find common themes across their different subjects, allowing each discipline to address the theme from its own perspective. The project maintained a focus on subject-specific content while working under an overarching theme. The overall name of the activity was population genetics which was the main focus in biology. In mathematics they used the Hardy-Weinberg equilibrium to calculate the expected frequencies of different genotypes in a population based on the observed allele frequencies which also was part of this population genetics. When analysing this case we find that the integration is done both with a focus on integration by biotechnology in a STEM subject domains approach. Each teacher maintained their subject-specific focus, ensuring that the academic rigor of each discipline was preserved, but in the same time the intention was also to work with the overall biotechnology theme about population genetics. This method highlights the importance of disciplinary depth while still fostering interdisciplinary connections through a shared subject domain theme from science. This thematic approach allowed students to explore biotechnology holistically while maintaining the academic rigor and depth of each discipline.

In conclusion, this case incorporates multiple integration approaches: integration through STEM subject domains, where biotechnology (population genetics) served as the central theme and therefore theme/context integration, by connecting the disciplines through a meaningful, real-world theme. Together, these approaches ensured interdisciplinary coherence while respecting the integrity of each subject, illustrating how thematic and domain-based integration can foster both depth and interconnectedness in STEM education.

Case 3: HTX Gymnasium

The third case takes place at an HTX gymnasium where five teachers from mathematics and other science subjects worked together on a STEM project centered around the common concept of "growth". This project employed a transdisciplinary approach, aiming to transcend traditional disciplinary boundaries and focus on a holistic understanding of growth.

The concept of growth was explored through multiple subjects, such as bacterial growth in biology, chemical growth processes in chemistry, biotechnological applications, and mathematical modeling of growth patterns leaned by towsing dices, all inspired of the processes of a waterwaste treatment plant. This case highlights how the STEM integration can be viewed through the Crosscutting Concept approach. The third case also exemplifies the context approach by framing the STEM project around the real-world concept of "growth," inspired by processes in a wastewater treatment plant. This context provided students with a practical and meaningful setting in which to explore growth through various disciplinary lenses. By connecting bacterial growth in biology, chemical growth processes in chemistry, biotechnological applications, and mathematical modeling of growth patterns using dice, the project situated abstract concepts within an authentic, applied environment. The wastewater treatment plant context not only grounded the learning experience in a relevant scenario but also demonstrated the practical implications of STEM knowledge in solving real-world challenges.

Case 4: Private Primary School

The final case 4 involves a school in south of Jutland in Denmark (Lower Secondary school 2), where six teachers of mathematics and science designed an activity in seventh grade where the students should design houseboats. In mathematics, students were tasked with creating precise scale drawings as working blueprints. The physics component involved discussions on density in relation to buoyancy. Additionally, students were introduced to the sustainability aspects of various construction materials. These interdisciplinary tasks were designed to integrate mathematical precision, physical principles, and environmental considerations within the design. The activity culminated in an exhibition of the students' houseboat models.

This case aligns in some way with the integration by theme and context-approach from Seidelin and Larsen (2021) because of the houseboat Context. On the other hand, there is also a specific emphasis on engineering in this activity, as the focus is precisely on the design and construction of houseboats, so we here also can see it as an integration by methods and integration by STEM subject (here engineering) domains.

In Table 1 below, we have consolidated the analyses. It is evident that there is often overlap between the different approaches to integration. While some approaches may be more dominant than others, it is also possible to consider whether one approach might serve as a starting point for initiating the integration process, with others evolving over time. However, we have chosen not to explore this aspect further.

Table 1. Overview of the four cases integration approaches

LabSTEM+	Integration approach
Case 1	Integration by methods, integration by STEM subject domains, integration by theme/context
Case 2	Integration by theme/context; integration by STEM subject domains
Case 3	Integration by crosscutting concepts, integration by theme/context
Case 4	Integration by theme/context, integration by methods, integration by STEM subject domains

4 Expanding the STEM integration model

Through our collaborative analysis and discussion of how various teacher groups managed to integrate the STEM subjects into an integrated activity, we discovered that the learning environment was also an integral part of the integration process. This element was not included in Seidelin & Larsen's (2021) model, and we argue here for the importance of this component across the different cases.

In case 1 where student should design racecars, the teachers facilitated the project by providing ample materials and guiding students through the engineering process. The physical learning environment played a significant role in shaping this process. For example, the diversity of materials, such as corks and straws, allowed students to explore different methods for constructing stable wheels, encouraging creativity and hands-on problem-solving. However, the role of the learning environment became particularly evident when an unexpected change disrupted the execution of the project. As one teacher noted, "It [the teaching] was moved from being in the auditorium to instead being in the hall, which we had otherwise planned for" (min 3.34, recording from the evaluation of the project). This shift in location introduced unforeseen challenges, highlighting the need for stability and predictability in the physical environment to support the structured methodological approach, showing that the physical learning environment was a key factor in planning the STEM activity.

In case 3 the teachers were working on planning growth as an important concept in the different subjects, because this is part of the curriculum, but sometimes in the planning of the STEM project, one teacher remembered a possibility for school classes to come and visit the local treatment plant. The visit to the local wastewater treatment plant therefor ended on played a crucial role in the planning and execution of the teaching, providing a real-world context that enriched the students' learning experiences, and being the guide for the teachers on how to approach the concept of growth in their teaching, inspired of the way the treatment plant deals with bacteria growth. The importance of the atypically learning environment was mentioned as being a catalysis of “a lot of fun” (interview min 6.27) and “a hook for the students to hang the concept of growth on” (interview min 6.38).

Even during the students’ final evaluations, where students presented their investigations in the form of a poster, they often followed the chronological processes observed at the treatment plant in their presentations. This approach allowed them to apply their interdisciplinary knowledge in a structured manner, deeply connected to the learning environment.

Finally, in case 4 the STEM activity was inspired by their local environment, with their city split into one part being at the main part of Jutland, and the other part on an nearby island, connected with a bridge, allowing houseboats as a ferally common residents for the city’s citizens. With a new, well-equipped STEM lab available at the school, the teachers decided to focus on designing and building models of houseboats, reflecting the prevalence of houseboats in their area. The presence of a new, well-equipped STEM lab at the school also played a pivotal role in shaping the teachers' planning and execution of the project. In the beginning of the project, the main coordinator from the school, pointed out that the new lab, could serve as an inspiration for the work in the LabSTEM+ laboratory. In that way, the STEM lab at the school provided a foundational learning environment that not only supported the technical aspects of the project (being a location where student would be able to find building materials and such) but also inspired creativity and innovation among teachers in planning the STEM project for the students. For the teachers, having access to specialized tools, materials, and equipment allowed them to conceptualize and design an activity that would otherwise have been difficult to implement in a traditional classroom setting. The lab's resources facilitated hands-on learning aligned with the interdisciplinary goals of STEM education. By anchoring the STEM activities in a familiar local theme, they enhanced the students' connection to the subject matter and demonstrated the practical applications of STEM concepts. However, this case also indicates that the special designed STEM learning environment played a crucial role for the approach on integrating STEM in their project. The group of teachers was initially very interested in how the interior design in the room and materials in the room could be integrated into STEM activities, frequently grounding their decisions in what could be accomplished within the STEM-lab and what made sense for their objectives.

In contrast, Case 2 demonstrated no discernible influence of the learning environment on either the planning phase or the actual instruction. Students were taught in conventional classroom settings, employing more traditional pedagogical approaches.

Whether it is the local context at the school (case 1, case 4), in the city (case 3, case 4), or the physical materials available in the classroom (Case 1, case 3 and case 4), each case emphasizes the importance of leveraging the immediate learning environment to enhance student engagement and understanding for the connection of STEM and the individual subjects. We found in the three cases that the use of the learning environment was a critical component of designing and developing successful STEM activities, but it also served as a factor for the students to remember the subject knowledge. By incorporating local contexts, STEM labs, and available materials, teachers could better create more immersive and relevant learning experiences for the students that integrated the disciplines. This approach aligns with experiential learning theories, which emphasize the importance of the learning environment (Keiding, 2010) and hands-on activities (Gardner & Tilotson, 2019) in deepening student understanding and retention of knowledge. Nicolini (2012) explicitly highlights that the material environment significantly shapes practices, influencing how both teachers and students interact with learning tasks, so by thoughtfully integrating material resources and hands-on opportunities, educators can create more dynamic environments that enhance engagement, creativity, and interdisciplinary learning.

4.1 Introduction to the fifth petal

From the analysis of the four cases in the LabSTEM+ project, it is evident that in three of the cases, the physical learning environment plays a crucial role in both the planning and execution of STEM teaching. The environment provides a tangible framework for the learning experience to unfold and take shape, acting as a foundational element that supports both the teaching process and the students' engagement. In the evolving landscape of STEM educational research, integrating the learning environment as a critical component is also proposed as a factor that offers a holistic approach to teaching and learning STEM (Svabo et al., 2024).

And with theoretical and empirical evident we therefore introduce a fifth approach to the four existing approaches, in the STEM integration model, such that it contains the approaches: integration by context/theme, integration by subject domain, integration by crosscutting concepts, and integration by the physical learning environment, by emphasizing the physical contexts in which STEM learning occurs. The analysis also indicates nuances of the approach of integrating STEM through the physical learning environment

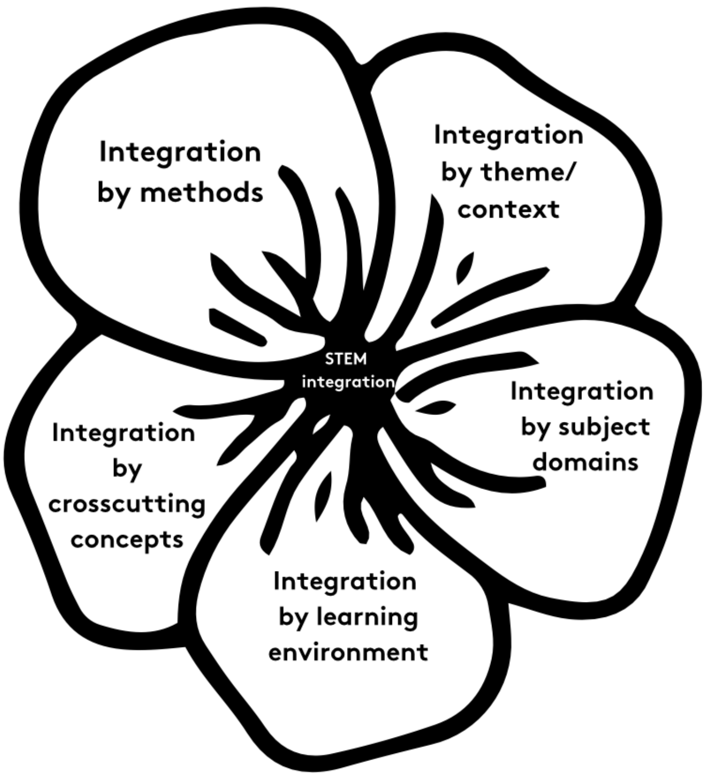
In Case 3, the teachers were inspired by the physical learning environment in a way that made it the foundation for the entire project theme: "growth." The local wastewater treatment plant became the starting point for interdisciplinary planning. Without considering the plant as a learning environment, the teachers might not have developed the diverse ways of approaching growth across subjects such as biology, mathematics, and physics. Visiting the plant also provided a memorable context for the students, enabling them to anchor their subject knowledge to a tangible experience. This demonstrates how the learning environment can act as both a conceptual and physical framework for STEM integration.

In Case 1, the learning environment was not central to the initial planning but became highly significant during the project's execution. An unexpected change in venue, from the planned auditorium to the school hall, created unforeseen challenges for the teachers. This shift in the physical learning environment disrupted the execution and introduced an element of chaos, as described by the teachers. The adaptation required by the new environment underscored the importance of considering the learning environment during both planning and implementation phases, as it directly influenced the teachers' ability to manage and execute the project effectively.

In Case 4, the entire project was shaped by the learning environment from the outset. The teachers began their planning by exploring the possibilities offered by their newly equipped STEM lab. The design and scope of the project, focused on building houseboat models, were driven by the tools and resources available in the lab. The space itself invited specific types of activities and provided the foundation for what was feasible in the project. This case exemplifies how the learning environment can actively shape the scope and nature of STEM teaching, serving as both a physical and conceptual starting point for planning.

These cases also highlight the varied roles the learning environment can play in STEM integration. In Case 1, it served as a thematic inspiration and a tool for memory retention; in Case 3, it became critical during execution due to unforeseen challenges; and in Case 4, it was the driving force behind the project's design and feasibility. These differences illustrate how the learning environment can influence the integration of the subject in STEM teaching, from shaping initial ideas to determining what is practical and engaging for students. In Figure 1, we have now revised the integration model to include five petals, with "integration by learning environment" added as a new component. This modification to the original model proposed by Seidelin & Larsen (2021) represents a more comprehensive understanding of the multifaceted nature of STEM integration in educational settings.

Figure 1. The flower has now been given an extra petal which includes the learning environment as an integration approach in STEM



5 Discussion

The integration of the learning environment as a fifth element within the STEM integration model significantly enriches the existing theoretical framework by emphasizing the active role of physical spaces in shaping educational experiences. However, its implementation requires deliberate planning and alignment with educational objectives to ensure it creates meaningful conditions for learning rather than becoming an incidental factor. As Gardner and Tilotson (2019) highlight, hands-on activities within appropriate environments foster deeper engagement and understanding, aligning with the experiential learning theories of Keiding (2010). However, the study suggests that, simply relocating a learning activity to a new setting is insufficient; instead, the learning environment must actively influence the teaching design, execution, and interdisciplinary connections of STEM projects. Using the physical learning environment actively it offers unique affordances that enhance engagement, creativity, and interdisciplinarity (Nicolini, 2012). For example, in Case 3, the wastewater treatment plant provided a tangible and memorable context for exploring growth across disciplines. This context grounded students' understanding and inspired teachers to develop interdisciplinary connections that might not have emerged in a traditional classroom setting. Similarly, in Case 4, the STEM lab's advanced tools and resources directly influenced the project's scope and design, enabling hands-on exploration and fostering innovative thinking. These examples align with Michelsen et al. (2017), who emphasize the importance of using real-world contexts to transform educational practices and promote meaningful engagement.

Furthermore, the learning environment supports long-term retention of knowledge by anchoring it in memorable experiences. In Case 3, the visit to the wastewater plant served as a mental reference point for students, connecting abstract concepts to real-world applications. This reflects Keiding's (2010) emphasis on situating learning in authentic contexts, which enhances both understanding and memory retention. Similarly, Case 4 illustrates how a well-equipped STEM lab can inspire creativity and shape the possibilities for interdisciplinary STEM activities, demonstrating the transformative potential of thoughtfully designed learning spaces.

For the fifth approach to be effective, educators must also consider its practical limitations. Case 1 highlights how unforeseen changes in the learning environment—such as moving from an auditorium to another room, can disrupt the execution of STEM projects. This underscores the importance of flexibility and foresight in planning, as well as the need for educators to adapt to the limitations and affordances of different environments. Additionally, addressing inequities in access to high-quality learning environments, such as STEM labs or field trip locations, is essential for broader implementation. As Michelsen et al. (2017) point out, professional development and systemic support are critical for empowering educators to recognize the potential of existing environments and design activities that maximize their educational value, even in resource-constrained settings.

Ultimately, the fifth approach is not merely about changing locations but about leveraging the environment as an active participant in the learning process. For example, in Case 4, teachers intentionally designed their project around the capabilities of their new STEM lab, letting the environment shape the learning activities and outcomes. By making the learning environment central to the planning and execution of STEM activities, educators can create richer, more interconnected educational experiences that bridge subject oriented theory to a real-world practice.

Future research should continue to explore the impacts of diverse learning environments on student outcomes and how it can be used to integrate the subject in STEM.

Limitations in the data collection process must be acknowledged. The study's focus on four cases, though diverse, may limit the generalizability of findings. While the qualitative data allows for analytical generalization (Yin, 2009), variability in institutional resources and teacher expertise should be considered when applying these insights more broadly.

For the fifth petal to be actively utilized in future STEM integration, concrete actions are necessary. Investments in infrastructure, such as adaptable STEM labs, and targeted professional development are crucial (Michelsen et al., 2017). Teachers must be supported in identifying the potential of existing environments and in designing meaningful activities, even within resource-constrained settings, to ensure that this approach can be effectively implemented and contribute to the holistic integration of STEM disciplines.

Conclusions

This study proposes an expansion of the STEM integration model by introducing the learning environment as a fifth approach, alongside the established methods of integration by context/theme, subject domain, method, and crosscutting concepts (Seidelin & Larsen, 2021). Drawing on empirical evidence from the LabSTEM+ project, the research sought to answer the question: What types of approaches to integrating STEM are practiced by teachers in the LabSTEM+ project?

The findings reveal that teachers in the LabSTEM+ project employed a variety of approaches, including integration by methods, context/theme, and crosscutting concepts, while also incorporating the learning environment as a key factor in STEM integration. Specifically, the cases highlights:

1. The learning environment can act as the conceptual foundation for interdisciplinary planning, as seen in Case 1, where the wastewater treatment plant shaped the entire theme of "growth."
2. It can become a critical factor during execution, as demonstrated in Case 3, where an unforeseen change in venue disrupted the project but underscored the importance of adaptability and intentional planning.

3. It can serve as a driver of project design, as in Case 4, where the new STEM lab inspired the teachers' planning and directly influenced the activities and scope of the project.

These findings indicate that the learning environment, whether through physical spaces, local contexts, or material resources, plays a central role in facilitating meaningful STEM integration. By providing tangible and memorable contexts, the learning environment enhances engagement, fosters interdisciplinary connections, and supports students in anchoring and retaining subject knowledge. This aligns with experiential learning theories that emphasize hands-on activities and situating learning in authentic contexts (Keiding, 2010; Gardner & Tilotson, 2019; Nicolini, 2012).

The integration of the learning environment into the STEM integration model enriches its applicability and relevance. It aligns with existing principles of STEM teaching, emphasizing real-world applications and participant-oriented approaches (Svabo et al., 2024). However, for this approach to be effective, it requires deliberate planning and systemic support. Schools with limited access to high-quality facilities may face challenges in fully adopting this approach, necessitating investments in infrastructure and teacher professional development (Michelsen et al., 2017).

In conclusion, the research demonstrates that the learning environment is not just a backdrop for teaching but an active participant in the design and execution of STEM education. By incorporating the learning environment as the fifth approach, the expanded STEM integration model provides a more holistic framework for understanding and implementing STEM education. Future research should further explore how diverse learning environments influence student outcomes and investigate strategies for overcoming challenges in resource-constrained settings. By embracing the learning environment as an integral component of STEM education, educators can create richer, more interconnected, and meaningful learning experiences.

Research ethics

Author contributions

M.S.: conceptualization, investigation, methodology, visualization, writing—original draft preparation, writing—review and editing
D.L.: conceptualization, investigation, methodology, formal analysis, writing—review and editing, project administration
C.S.: methodology, conceptualization, funding acquisition, supervision, writing—review and editing, project administration.

All authors have read and agreed to the published version of the manuscript.

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Institutional review board statement

The research did not involve participants under the age of 15, and therefore did not require review by an institutional research ethics board.

Data availability statement

The data supporting the reported results are not publicly available due to privacy and ethical restrictions. Access to the data is restricted to ensure the confidentiality of the participants.

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Conflicts of interest

The authors declare no conflicts of interest.

References

Artigue, M. & Blomhøj, M. (2013). Conceptualizing inquiry-based education in mathematics. *ZDM*, 45(6), 797–810.

Bertel, L. B., Møller Jeppesen, M., & Lisborg, S. (2023). Problembaseret læring på tværs af uddannelseskæden: Hvordan kan vi styrke overgange i STEM gennem arbejdet med autentiske problemer? *EMU* Danmark Læringsportal. https://www.emu.dk/htx/teknikfag/overgange/problembaseret-laering-paa-tvaers-af-uddannelseskaeden?b=t432-t481

Brown, A.L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *Journal of the Learning Sciences,* 2, 141–178.

Bybee, R.W. (2018). *STEM Education Now More Than Ever*. NSTA Press.

Carr, W. & Kemmis, S. (2005). Staying Critical. *Educational Action Research*, 13(3), 347–358.

Doğan, M. F., Gürbüz, R., Erdem, Z. Ç., & Şahin, S. (2019). Using Mathematical Modeling for İntegrating STEM Disciplines: A Theoretical Framework. Türk Bilgisayar ve Matematik Eğitimi Dergisi, 10(3), 628–653.

Gardner, M., & Tillotson, J. W. (2019). Interpreting integrated STEM: Sustaining pedagogical innovation within a public middle school context. *International Journal of Science and Mathematics Education*, 17(7), 1283–1300.

Guzey, S. S., Moore, T. J., & Harwell, M. (2016). Building up STEM: An analysis of teacher-developed engineering design-based STEM integration curricular materials. Journal of Pre-College Engineering Education Research (J-PEER), 6(1), 2

Keiding, T. B. (2010). Rummet som didaktisk kategori. *Uddannelsesnyt,* 21(3), 4–9

Klausen, S.H. (2011). *På tværs af fag: Fagligt samspil i undervisning, forskning og teamarbejde*. Akademisk Forlag.

Larsen, H.H. & Svabo, C. (2002). *Fra kursus til kompetenceudvikling på jobbet*. Jurist- og Økonomforbundets Forlag.

Larsen, D. M., Kristensen, M. A., & Svabo, C. (2024). Expanding the horizons of mathematics in STEM: Diverse mathematical roles in STEM activities. In Anderson, J., Makar, K. (eds) *The Contribution of Mathematics to School STEM Education: Current Understandings* (pp. 85–102). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-97-2728-5_5

Larsen, D. M., Lindhardt, B. K., & Misfeldt, M. (2022). Undersøgende matematik. I S. Skov Fougt, J. Bundsgaard, T. Hanghøj, & M. Misfeldt (red.), *Håndbog i Scenariedidaktik* (s. 203–216). Aarhus Universitetsforlag

Nadelson, L. S., & Seifert, A. L. (2017). Integrated STEM defined: Contexts, challenges, and the future. T*he Journal of Educational Research: Teaching and Learning Integrated STEM using Evidence-Based Practices,* 110(3), 221–223.

Nicolini, D. (2012). *Practice theory, work, and organization: An introduction*. Oxford University Press

Nielsen, K., Sillasen, M. K., & Daugbjerg, P. S. (2017). Engineering-svaret på naturfagenes udfordringer?. *MONA, Matematik Og Naturfagsdidaktik*, (2), 64–82.

Maass, K., Geiger, V., Ariza, M. R., & Goos, M. (2019). The Role of Mathematics in interdisciplinary STEM education. ZDM, 1–16.

Michelsen, C., Petersen, M.R. & Ahrenkiel, L. (2017). Laboratoriemodellen – kompetenceudvikling med fokus på forandring af praksis. *MONA – Matematik- Og Naturfagsdidaktik*, (4), 39–55.

Møller, M. (2022). En STEM-didaktik er nødvendig hvis STEM skal være mere end et slogan. *MONA – Matematik-Og Naturfagsdidaktik*, (1), 59–64.

Sanders, M. (2009). STEM, STEM education, STEMmania. *The Technology Teacher, 68*(4), 20–26.

Savery, J. R., & Duffy, T. M. (1995). Problem based learning: An instructional model and its constructivist framework. *Educational technology*, 35(5), 31–38.

Seidelin, L & Larsen D.M. (2021). STEM-integration – mere end en målsætning for grundskolen? Emu.

Sillasen, M. K., Daugbjerg, P. S., & Nielsen, K. (2017). Engineering-svaret på naturfagenes udfordringer?. *MONA-Matematik-Og Naturfagsdidaktik*, (2).

Svabo, C. & Shanks, M. (2014). Experience as Excursion: A Note towards a Metaphysics of Design Thinking. I P. Benz (red.), *Experience Design: Concepts and Case Studies* (s. 23–32). Bloomsbury Academic.

Svabo, C., Larsen, D. M., Borch, K. B., Svendsen, M. W. H., & Kristensen, M. L. A. (2024). S*TEM-didaktik: med fokus på matematik til grundskole, gymnasie o g dagtilbud*. Syddansk universitetsforlag

Yin, R. K. (2009). *Case study research: Design and methods* (Vol. 5). sage.