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Practice-based holistic STEM teaching in VET

Increasing students' participation opportunities

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Abstract

This article examines the significance of practice-based holistic STEM teaching in vocational education and training and how it can enhance students' motivation and learning in STEM subjects. The study shows that STEM teaching, which incorporates vocational practice, can motivate and include more student groups, including those with negative experiences from previous schooling. The article distinguishes between 'imagined vocational practice' and 'experienced vocational practice'. The article argues that the latter, which involves concrete, physical experiences, has the potential to strengthen students' motivation and increase the opportunities for participation in STEM teaching.

When students have the opportunity to physically experience their future vocational practice, it can help enhance their engagement and improve their learning outcomes in STEM subjects. Practice-based and holistic teaching makes abstract concepts more concrete and therefore easier for students to relate to their future vocation. The empirical analyses in the article are based on the research and development project 'Holistic STEM Teaching in VET'. The data collection was carried out through observations and qualitative interviews as well as a national survey. Additionally, an international literature review was conducted. The analysis indicates that when teaching initially involves experienced vocational practice and later introduces imagined vocational practice, it can help students understand and appreciate the theoretical aspects of STEM subjects.

Practice-based holistic teaching requires interdisciplinary collaboration between STEM teachers and vocational teachers, as well as organizational structures that facilitate this. Teachers' collaboration supports students' sense of meaning in STEM subjects, as it qualifies the inclusion of relevant practice across vocational and STEM subjects. The article concludes that practice-based holistic STEM teaching, which is based on concrete vocational experiences, not only increases motivation and learning among students but also contributes to more inclusive and meaningful teaching that can engage a broader range of student types.

Keywords: STEM, holistic teaching, practice-orientation, practice-based, participation opportunities, collaboration

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Background

Danish VET colleges face significant challenges in retaining students who choose vocational education and training (VET) (Schoop, Andreasen, & Mikuta, 2023). There are various reasons for this, but fundamentally, it calls for a focused effort to strengthen and maintain students' motivation and learning throughout their educational journey. STEM subjects, in particular, challenge many students' motivation and sense of meaning in their education (Andersen, Benthien, Hersom, & Hjermov, 2022). This article suggests that practice-based and holistic teaching in STEM subjects in VET can be a significant contribution to this effort.

In Danish VET, it is a political requirement that teaching is practice-based and holistic. Students' education alternates between school periods and training in companies, and holistic education is based on an ambition to connect both theory and practice in students' school periods and ensure coherence between school periods and their workplace based training (BEK nr 953, 2023; LBK nr 40, 2024). However, many STEM teachers feel that they lack the time and framework to collaborate with vocational teachers to develop teaching that is practice-based and vocationally relevant. Additionally, teachers need knowledge and ideas to be able to organize holistic teaching (Slottved, Larsen, Ladekjær, & Koudahl, 2019).

Practice Based Holistic Teaching

This article is based on the research project 'Holistic STEM Teaching in Vocational Education and Training' (Andersen et.al., 2022; Andersen, Benthien & Hersom, 2024). The project contributes knowledge on how VET teachers across subjects can support students' motivation and learning in STEM teaching. The project points to which didactic choices and considerations can strengthen the practice-based holistic approach to teaching and how teachers across STEM subjects and practical subjects can collaborate to strengthen STEM teaching through the inclusion of practice (ibid.).

In this article, practice-based holistic STEM teaching is defined as a form of teaching that is based on and directed towards the given practice for which the students are being trained. In this teaching form, the theoretical STEM subjects are integrated holistically with the students' relevant practice to increase students' understanding of the theoretical aspects of practice (ibid.).

The analytical results in the article are based on data collected during the initial part of the students' educational journey. Students enter vocational education with very different experiential backgrounds. Some students have concrete experiences from and with the profession, for example through unskilled work or personal interests, while other students are entirely new to the field and thus unfamiliar with the profession's practices. Students' prior experiences with both the vocation's practices and STEM subjects are significant for teachers' organization of holistic education and therefore have substantial implications for the analysis's conclusions.

The article indicates that many teachers across subjects need greater insight and understanding of how practice-based holistic teaching as a didactical principle can be integrated into STEM teaching because this is a way to increase and strengthen multiple student groups. The main purpose of the article is to provide an analysis of how vocational practice can be integrated into STEM teaching in various ways that support and enhance holistic teaching and

strengthen multiple student groups' opportunities for participation in teaching and learning. Strengthened holistic teaching in STEM subjects is a political requirement, a desire from teachers, and a potential in the effort to retain students in VET (Benthien & Hersom, 2023). Based on the project's results, this article argues that a strengthened focus on practice-based holistic teaching can contribute to creating more opportunities for participation in STEM teaching in VET.

This leads to the following research questions: How can practice-based holistic teaching support VET students' experience of STEM subjects as being relevant and motivating? And how can VET teachers strengthen multiple student groups' opportunities for participation in the STEM subjects?

Research in Holistic Teaching in STEM Subjects – state of the art

This section outlines and brings together the theoretical foundation on which the article is based. It points out some important findings in a systematic literature study that has been carried out in the mentioned research project 'Holistic STEM Teaching in Vocational Education and Training' (Andersen et.al., 2022; Andersen et.al., 2024). Findings that relates to the research question in this article in different ways.

STEM teaching and holistic teaching are well-researched topics within international research both within and outside of the context of VET. In Sweden, several studies in recent years have examined STEM subjects in VET context. One of these studies indicates that it is a complex task to link the subject of mathematics with construction-related subjects (Bellander, Blaesild, & Boistrup, 2017). The study suggests that some mathematical topics can have independent learning value (ibid.). This article aims to demonstrate how STEM subjects can be connected to practical subjects. However, it is relevant to point out that the goals and content of STEM subjects themselves are essential to consider, and in some cases, there may be STEM-specific pedagogical and didactic arguments for organizing STEM teaching with a single subject focus in mind. The article's analysis subsequently indicates that practice-based holistic teaching can be organized based on either the STEM-specific goals or the vocational practice.

Several international studies contribute knowledge on how teaching organized as problem-based learning can enhance students' learning and motivation for various forms of STEM teaching. One study shows, for instance, that problem-based learning in biochemistry contributes to higher academic standards among students (Tarhan & Ayyildiz, 2015). A Welsh study points out that problem-based learning motivates participants in different types of mathematics courses, particularly when mathematics is linked to real existing problems, and a study from Taiwan suggests that problem-based learning is a way to develop and learn relevant STEM competencies (Hall, 2014; Lou, Shih, Ray Diez, & Thseng, 2011). Finally, an American study highlights the potential of integrating STEM and practical skills through experimental learning in agricultural education, where students gain hands-on experience through practical problem-solving (Gill, 2011). A Swedish-Finnish study highlights the dilemmas between catering to the practically-oriented vocational students and the requirement for teachers to spend time on emotional support and motivation (Rosvall, Hjelmér, & Lappalainen, 2017).

The research project underlying this article also points to the potential of organizing holistic

STEM teaching based on problem-based learning. When students experience being able to use STEM content to solve concrete problems from a given vocational practice, many describe the teaching and subject as meaningful and motivating (Andersen et.al., 2022; Andersen et.al., 2024). The article's analysis particularly focuses on how teaching increases participation opportunities as students gain concrete and physical experiences with their future vocation through the processing of STEM content.

Organizing teaching in a way that supports students in addressing authentic and relevant problems from vocational practice requires, according to another Swedish study, that teachers identify areas in vocational practice where students can apply mathematics (Frejd P. , What is the role and place of mathematics education in (swedish) vocational education?, 2018). This creates an awareness that meaningful connections between theory and vocational practice require teachers to collaborate across subjects and potentially also with practitioners in the vocation, as several studies also point out (Margot & Kettler, 2019; Stone, 2007). A German study, in line with considerations of interdisciplinary collaboration, suggests that to organize teaching that meets competency needs, one must identify used competencies in practice and thus collaborate with professionals in the field (Gessler & Howe, 2015).

Collaboration among teachers in Danish VET also has a decisive impact on the quality of holistic teaching in STEM subjects (Benthien, 2023; Benthien & Hersom, 2023). The terms for collaboration vary in the different types of vocational education, and this article contributes knowledge on how terms and structure and possible collaboration interfaces can be either supportive or undermining in relation to the development of holistic teaching.

A third Swedish study points to the same and further indicates that teachers must be educated in the mathematical skills actually required by the vocation – visits to workplaces provide teachers with necessary insights. In Sweden as well, despite a focus on vocational relevance, mathematics education is often closely tied to the textbook – possibly due to exams. This happens at the expense of students' motivation (Muhrman, Inget klöver utan matematik : En studie av matematik i yrkesutbildning och yrkesliv, 2016). The same study suggests that various types of vocational practice has undergone such significant changes that practical skills alone are no longer sufficient, and studies indicate that in many vocations, mathematics can be an equally important competency (Muhrman & Lundberg, 2015). STEM teachers in Danish VET colleges come with very different experiences and from various educational backgrounds. This article does not delve into the potential of formal further education for STEM teachers but focuses on how collaboration among teachers across different subjects can support informal competency development for both vocational teachers and STEM teachers. The collaboration among teachers contains potentials to include more groups of students in VET when the teachers collaborate and share their experiences with different ways of working with authentic practice in education.

All in all, the selected research studies show potentials in holistic teaching in STEM subjects. First of all it is important to note that not all studies conclude that holistic STEM teaching is the way to motivate VET students. Some studies indicate that for example mathematical topics can have an independent learning value for some groups of students. It is also important to notice that problem-based learning can enhance students' learning and motivation in the STEM subjects. Studies show potentials in organizing holistic STEM teaching based on problem-based learning. When VET stu-dents are being able to use a STEM content to solve authentic and

relevant problems based on their vocational practice it seems to have an motivative influence on some groups of students. This also requires a close collaboration between teachers with vocational education and education within STEM subjects in order to ensure that different competences is represented

Method and Data Basis

As mentioned, this article is based on the research project "Holistic STEM teaching in Vocational Education and Training (VET)" (NCE, 2020; Andersen et.al., 2022; Andersen et.al., 2024). The analysis of the article is based on selected data from the project.

In connection with the categorization and analysis of data in the research project, it became evident that 'vocational practice' can be understood and applied in multiple ways. The aim of the research project was to define different approaches to holistic teaching and, therefore, it did not dwell on developing a nuanced understanding and definition vocational practice.

These data, however, have been selected for the analysis in this article. The selected data thus consist of excerpts from the interviews conducted as part of the research project. Excerpts that contribute to a nuanced understanding of how vocational practice can be understood and integrated into STEM teaching in VET. Furthermore, the data is selected based on their contribution to understanding how the didactic application of vocational practice in teaching can create different participation opportunities for the student in VET. The results presented in this article therefor primarily stems from an analysis of the data from the qualitative interviews with leaders, teachers, and students.

The methodological design consists of a literature review, a national survey, qualitative interviews with leaders, teachers, and students from seven different VET programs, and observations of STEM teaching at the same programs. The purpose of the methodological design was to generate knowledge about holistic and practice-based STEM teaching in VET (Andersen et.al., 2022). The purpose of this methodological triangulation was to enrichen the findings withdrawn from data collected through both qualitative and the quantitative methods.

The article is based on interviews conducted at three levels: students, teachers, and leaders. A primary ethical consideration in this context has been to anonymize the respondents in order to enhance their opportunities to express genuine experiences with practice.

The literature review had several objectives. Firstly, it identified relevant national and international research and practical knowledge regarding holistic teaching in VET. The studies mentioned in the section above are examples of some important results of the literature study that relates to the aim of this article. The analysis in the article is based on the systematic literature study on practice-based holistic STEM teaching. Secondly, the literature study informed the design of the survey and interview guides for the qualitative interviews (ibid.).

The national survey examined students' motivation for, learning outcomes from, and experiences with STEM teaching. The survey was distributed to all students in the basic course of three main areas: Technology, Construction, and Transport; Food, Agriculture, and Experiences; and Care, Health, and Pedagogy. In total, 63 VET colleges received the survey, and 31 colleges participated with at least one student response. The survey was answered by 925 respondents. The representativeness of the survey results was treated with caution, but the responses

contributed to identifying overarching trends across data sources (ibid.).

The qualitative data consist of transcriptions of a total of 20 single and group interviews. The respondents included six leaders, 20 teachers, and 32 students, along with written observations of a total of seven days of STEM teaching (ibid.). The qualitative data provide insight into the considerations, efforts, and experiences of leaders, teachers, and students with motivating holistic teaching in STEM subjects. The interviews were semi structured, and the questions were written in interview guides. All of the interviews were transcribed, coded and analysed. The answers from the respondents addresses a number of different themes relevant to the focus of the research project. Deeper analysis of the interview data and the themes lead to important insights about holistic teaching between imagined and experienced vocational practice which is the focus of this article.

The implemented research approach resulted in three overall themes that are particularly significant for holistic STEM teaching: 1) the form and content of the teaching, 2) the framework of the teaching, and 3) the teacher's role. Each of these themes includes several focal points regarding how teachers can approach the development of holistic STEM teaching (ibid.). This article is based on selected data from all of the three themes.

At the end of the research project empirical data were collected through 32 qualitative single and group interviews with teachers and students who participated in the developed practice-based and holistic teaching courses (Andersen et.al., 2024). The purpose of the qualitative interviews was to gain insights into teachers' experiences and reflections on developing holistic STEM teaching and students' experiences and reflections on participating in the same. This contributes knowledge on how to organize practice-based, holistic teaching that enhances students' motivation for and learning in STEM subjects in VET. It also provides a basis for analyses of different ways to include and motivate more student groups in STEM subjects by practice-based teaching. Additionally, it provides insights into the organizational barriers that might exist for developing and implementing holistic STEM teaching.

Holistic Teaching Between Imagined and Experienced Vocational Practice

This analysis is based on the empirical data mentioned above. It conveys how providing students with concrete experiences of their vocational practice in STEM teaching can help create more participation opportunities for various student groups in VET. The analysis illustrates that practice-based, holistic STEM teaching can invite students into an imagined vocational practice or a physically experienced vocational practice in different ways. The main point of the analysis is that when practice-based, holistic teaching is based on an imagined vocational practice, it caters to students who, for various reasons, are able to imagine a practice that is not physically present in front of them. On the other hand, when the practice-based, holistic teaching allows students to *experience* a vocational practice concretely and physically, it includes a wider range of students—especially those who have motivational and learning needs to see, feel, and otherwise experience a physical practice in teaching. These students, for various reasons, are not as capable of imagining a practice that becomes too abstract.

Based on the research project "Holistic STEM teaching in Vocational Education and Training

(VET)" (Andersen el.al., 2022; Andersen et.al., 2024), this article points out that particularly two groups of students are included in holistic teaching when it successfully creates real experiences of a vocational practice closely related to a given STEM subject. Firstly, it includes the students that are primarily motivated to learn their future vocation by being part of and immersed in the physical and practical environment of the vocation. These are the students that are motivated by learning experiences where the teaching reflects the concrete vocational physical practice they will enter after completing their education. Secondly, it includes students that encounter STEM subjects with negative self-efficacy expectations due to previous poor learning experiences in these subjects.

A teacher in a carpentry program describes these two types of students as follows:

> We might get some types of students who have gone through elementary school and think now they want to go out and work, and because of that, they choose a vocational education. And then they encounter math again, and they quickly face this barrier, resistance, because maybe they were never fans of math in elementary school. We also see some who had good experiences with math in elementary school and simply do not understand why they need to take it again (vocational teacher, carpentry program).

Both student groups are characterized by being motivated by their future vocation, but the learning barriers are different. The resistance to—in this case, mathematics—in one student group is linked to their dissatisfaction with math in their previous schooling. The other student group does not necessarily have bad experiences with math from earlier schooling but has chosen vocational education because they want to engage in their future work practice rather than continue learning the same content and in the same ways they were accustomed to in their previous schooling. The two student groups apparently have different reasons for the lack of motivation in math but they have in common that they want to work with their vocation in practice.

What is Practice-Based Holistic STEM Teaching?

Many teachers in STEM subjects point out that they lack the structures enabling and ideas on how to strengthen the connection between STEM subjects and students' future vocational practices (Slottved et al., 2019; Andersen et.al., 2022). A lack of knowledge and collaboration are some of the reasons why practice-based holistic teaching is not always a driving principle in vocational STEM teaching. This results in STEM teaching being conducted without a link to practical application. The teaching takes place isolated from the training programs' workshops and other authentic practice contexts, and it does not always include examples and cases related to the vocational practice the students are training for. In such cases, the teaching is not considered practice-based holistic. This concept is illustrated in the lower corner of the model below, representing STEM teaching with 'no vocational practice.'

Several teachers highlight the difficulty of finding meaningful content where the practices of the vocation and the content of the STEM subject can meet. This article argues that practice-based holistic teaching has great potential to increase participation opportunities and motivation for the two mentioned student groups. This is particularly evident when practice-

based holistic teaching is related to two different ways of integrating vocational practice into STEM teaching: imagined vocational practice and experienced vocational practice.
To speak of something as being practice-based holistic teaching, there must be a collaboration between the STEM subject and the practical subjects in connection to the vocational practice. This article unfolds the analysis that practice-based holistic STEM teaching can take place on a continuum between 'imagined vocational practice' and 'experienced vocational practice.' The model below illustrates how teachers in VET can work with students' attainment of learning goals by designing teaching that positions itself somewhere between the continuum's two poles.

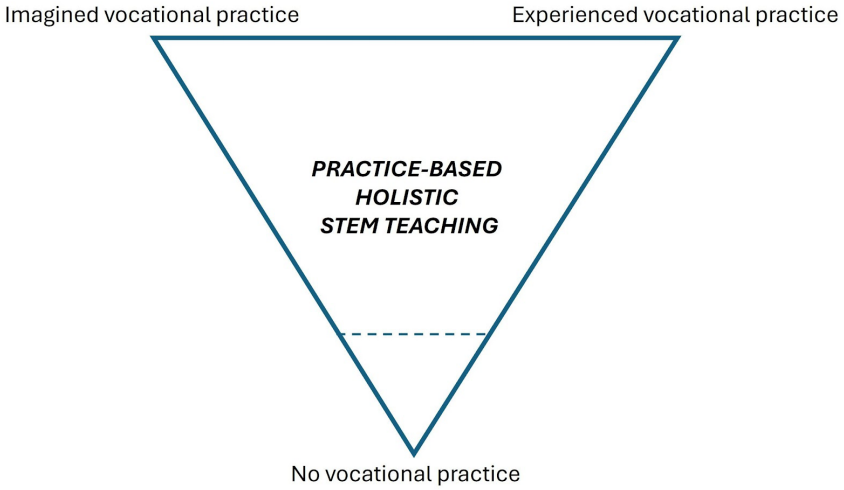

Figure 1. Definition of how teaching can be based on STEM learning goals

The model aims to define how teaching can be based on STEM learning goals in different ways. As mentioned, the lower corner of the model states no vocational practice.' The dotted line illustrates that this corner of the triangle is not defined as practice-based holistic teaching since the teaching here is planned and conducted without involving the vocational practice the students are training for. According to the article's definition, it is only considered practice-based holistic teaching when the teaching, to some extent, invites students into either an 'imagined practice' (the left corner of the model) or an 'experienced practice' (the right corner of the model). Practice-based holistic teaching is thus defined as the types of teaching that occur above the dotted line in the model.

When Holistic STEM Teaching Happens Through the Imagination of Practice

Practice-based holistic teaching can be based on what the article defines as an imagined vocational practice (the left corner of the model). When STEM teaching invites students into an imagined practice, it, for example, uses cases and examples from the vocation without the students being physically present in a vocational practice. When practice is included as an imagined practice, students and the teacher talk and write about the practice without being physically present in it and without experiencing it through touch, smell, or other bodily senses. This approach has several advantages, as the teacher can describe and discuss the students' future vocation. However, when practice-based holistic STEM teaching incorporates an 'imagined practice,' it can exclude groups of students who are motivated by experiencing a concrete

vocational practice. Like the students who can be defined as to belong in one of the two above mentioned groups. Additionally, students who do not yet have practical experiences, regardless of how they prefer learning, may find the imagined practice difficult because they lack concrete bodily experiences and tangible experiences to relate to.

When Holistic STEM Teaching Happens Through the Experience of Practice

The two student groups could potentially benefit in terms of motivation and learning from teaching that invites them to experience vocational practice (the right corner of the model). This involves integrating STEM teaching directly into vocational practice by conducting it in physical practice environments. This exemplary form of learning through experienced vocational practice often occurs during student's workplace-based training because this is where the physical environments are present, but it can also be approximated and occur in vocational STEM teaching. STEM teaching can mimic student's workplace-based training when conducted in a workshop at the school, for example, where the teaching of STEM content takes place directly at a car engine or where the teaching of fertilizers happens directly in the field. In such cases, students' work to acquire STEM content happens through experienced practice.

The Surroundings of Teaching Matters for the Incorporation of Practice

A given form of practice-based holistic teaching in VET can thus be placed in various positions in the triangular model. It can be situated somewhere between 'experienced vocational practice' and 'imagined vocational practice,' or it can be closer to the bottom corner where there is 'no vocational practice.' The closer a teaching situation is to the bottom corner, the more the teaching is based on the learning goals of the STEM subject.

Analyses from the research project show that practice-based holistic STEM teaching cannot always occur in 'experienced vocational practice' but must also necessarily be based on 'imagined vocational practice.' Furthermore, it can vary whether the STEM subject defines the incorporation of either imagined or experienced vocational practice and thus the content of the teaching, or whether practice defines the content of the teaching and thus which STEM learning goals can be worked with. This is mainly for three reasons. Firstly, it is often not practically possible to conduct all holistic teaching in a practice that supports concrete and physical experiences, as classroom settings and workshop facilities, as well as collaboration opportunities, do not always allow this. Secondly, for some students, there may be a learning benefit in training and developing their level of abstraction and imagination by working with an 'imagined vocational practice.' Thirdly, the learning goals for STEM subjects cannot always be met and found in experienced practice, as there may potentially be content and goals in certain STEM subjects that cannot be fulfilled in teaching when it only occurs in experienced practice. It is particularly significant to recognize that the development in vocations means that, for example, mathematical competencies can have just as much value as specific practical skills (Muhrman & Lundberg, 2016; Blaesild et al., 2017). This analysis is based on the idea that while practice-based holistic teaching emphasizes the value of incorporating practice and being aware of its nature, some holistic teaching must more significantly focus on the subject's goals and content rather than the goals and content of other subjects.

The teachers' own experiences and competencies play a significant role in incorporating practice (Slottved et al., 2019; Andersen et.al., 2022). A teacher without knowledge or experience regarding the students' future vocations may have difficulty imagining a vocational practice, making it challenging for these teachers to organize teaching where students are invited to experience vocational practice.

The main point of this article, as mentioned, is that teaching that provides students with concrete experiences of vocational practice can include and motivate more students. Therefore, it is significant that practical-based holistic STEM teaching in the early stages of students' educational journeys is based on 'experienced practice,' and incorporates 'imagined practice' later in the process. The imagined practice may need to be incorporated due to the aforementioned factors, but the article argues that starting teaching courses within an experienced practice can enhance students' perception of the relevance of STEM subjects since they have concrete physical practice examples to anchor their motivation and learning. Students can potentially achieve greater and quicker mastery experiences with STEM subjects if introduced to mathematics through concrete experiences related to their future vocation. This perspective is important partly because earlier studies indicate that when students work with and experiment using applied mathematics rather than purely theoretical mathematics, it can increase their self-efficacy and counteract the anxiety some or many students have from previous schooling (Sublett & Plasman, 2017).

Experiences in Professional Practice Can Make the Abstract Meaningful

The article is based on analyses that, as mentioned, show that the connection between STEM subjects and experienced vocational practice can motivate and include a broader range of students in the teaching process. Students may perceive STEM subjects as abstract and difficult to grasp, which for some of them is related to negative experiences from their earlier schooling. They carry these negative experiences with them into subjects like natural science, biology, and chemistry. A student from a watchmaking education program puts it this way:

> (…) none of us wanted to be a scientist or anything within natural sciences, it was more about those aiming for a good grade to get into various education programs; they really put effort during that half year. Beyond that, it was just something we had to get through, to be completely honest. So, most of us did what needed to be done to just pass the subject to move on. There wasn't much interest in it.

In the quote, the student explains that natural science was simply something to get done with and that the student viewed the subject merely as a necessary evil to advance in their education. The student does not see the subject as important in the context of a specific practice. According to the student, natural science is only meaningful if one needs the grade for admission to a particular education program or if one wants to become a 'scientist.' The subject's value remained abstract, and its practical applications were not evident to the student.

A practice-based holistic STEM teaching in 'experienced vocational practice' particularly aims

to support students' perceptions of the subjects' usefulness and direct application in relation to their future vocation.

How Physical Environments Can Enhance the Experience of Vocational Practice in Teaching

Encountering traditional physics classrooms, which resemble the learning environments students have previously experienced, can challenge the motivation of some students in STEM subjects (Andersen et.al., 2022; Andersen et.al., 2024). Studies further suggest that the physical environment in which students learn can have a significant impact on their motivation and learning (Frejd & Muhrman, 2020). Analysis of data from the research project shows that students I VET, especially those in the previously mentioned groups, are particularly motivated by a physical engagement with their future vocation. It is, therefore, crucial for teachers to consider how the "pedagogical scenography" can support practice-based, holistic teaching grounded in the experience of vocational practice. Abstract phenomena, such as plant life cycles and Ohm's law, can become tangible experiences when explored in workshops, nature, or company visits as alternative learning environments.

An example of this is the work on acid-base relationships in the previously mentioned natural science subject within a watchmaking education program. Here, acid-base reactions are embodied by having students create cleaning solutions for watches that need the correct pH balance to clean small components without damaging the parts. This teaching occurs in a workshop familiar to the students, and this kind of pedagogical scenography supports their sense of being part of the watchmaking trade and vacation.

Another example of STEM teaching providing experiences of vocational practice is found in gardening training program, where the biology teacher arranged lessons in the school's outdoor areas. This allowed students to have concrete experiences related to calculating the humus content in soil samples.

> For example, when we've had to dig up soil samples and determine the humus percentage in them. (...) It becomes exciting, and the more you have to document things, the more you remember them. Actually it's where I've done the best and gotten the highest grades, it's where I've been allowed to physically engage and have it in my hands (student, gardener).

When teaching takes place in a physical setting that reflects the vocational environment, it caters to various student groups' needs to see the value of the subjects. Teaching that gives students a concrete experience of the vocation's practice can potentially support such clear connections and constitute an important didactic perspective in the ambition to provide students with positive mastery experiences in STEM subjects.

Relocating natural science subject to the workshop also has the advantage that when students become curious about what happens if a watch component is placed in a basic cleaning solution, they can find the part, make the cleaning solution, and experiment with the question in a concrete physical practice. This exploration can help them seek answers to their questions. A related study indicates that project- and problem-based learning can reduce the fear of

mathematics, as this approach to the subject highlights its practical value (Tseng, Chang, Lou, & Chen, 2013).

Practice-Based Holistic Teaching Can Also Take Place in an Imagined Vocational Practice

A crucial task for VET programs is to support students in linking the abstract with the concrete—integrating theory and practice. As mentioned previously, practice-based holistic teaching can also occur when teachers collaborate to use examples and cases that describe situations from the student's vocational practice. In imagined vocational practice, examples are used in teaching that more or less directly relate to the vocation and involve discussing and/or reading about practice without a form of physical materiality. Examples and cases can be either fictional and/or something that could realistically occur in genuine vocational practice.

Working with an 'imagined vocational practice' can be a didactic tool to train students' imagination, and it can be a useful tool when it is not practically possible to conduct teaching in an experienced vocational practice. Furthermore, as noted, not all learning goals for STEM subjects can be met in a physically present practice. For this reason, practice-based holistic teaching via imagined vocational practice can be the right didactical choice for students for whom it is sufficient to be able to imagine the practice. This is shown by analyses of data generated in the research project. For example, it is seen that students can benefit greatly from working with cases that represent relevant issues they will face as skilled workers. It requires that students' imagination can connect issues to fictional contexts that still make sense to them and create a sense of practice relevance.

This can be supported through the use of examples, cases that invite students into the vocation. For instance, the study's interview data show that when examples and knowledge from natural sciences about the composition of nutrients are included, it can enhance the future social and healthcare assistant's understanding of the direct relevance to the work of correctly handling food for vulnerable citizens. Instead of having the future social and healthcare assistant work with isolated learning goals in natural sciences concerning, for example, the composition of nutrients, working with cases prompts them to relate to concrete and realistic meals for citizens with diabetes.

Imagined cases and examples of practice can get students to create connections between STEM subjects and the vocation. For example, insight into the periodic table from cases and examples in chemistry education can lead watchmaking students to understand that this knowledge is necessary to comprehend the watch's various components. Instead of memorizing the periodic table as rote learning, making it relevant to watch components can create engagement and explain why the subject requires an understanding of different elements. These cases and examples can thus be central in working with the periodic table. A natural science teacher in the watchmaking program explains:

> So, when I talk about the periodic table, I always take as a starting point the elements that I know exist in our vocation, and that I know they recognize. Because then it's not so abstract (natural science teacher, watchmaking program).

The above examples do not take place in authentic, physical practices, but they use imagined practice like situations and issues likely to occur in the students' vocation. Here, STEM subjects are used to explain and motivate different practice aspects in the teaching, and they appear thus as tools for students' understanding of practice rather than just being abstract concepts and an addition to a practice area (Bellander et al., 2017).

Students' Use of Imagination

A significant point of this analysis is that not all students possess the ablitity to imagine practice required to perceive the relevance of STEM-related cases and examples. For some, it will require an even closer physical connection to practice. For instance, a social and health care assistant might learn through role-playing or simulation dolls, or a watchmaking student may learn by holding the watch in their hands and understanding the components via the periodic table. In the latter case, less imagination is needed, making it easier for many students to see the direct practical relevance of the STEM subject. When practice-based holistic STEM teaching is planned and conducted based on concrete physically experienced vocational practices, it can motivate those students who need to see and feel the vocational relevance of the respective STEM subject.

Practice-Based Holistic Approach Requires Interdisciplinary Collaboration

Practice-based holistic teaching using experienced vocational practice, as previously mentioned, supports increased participation opportunities for students with negative expectations toward STEM subjects and for other students motivated by learning through experienced practice. At the same time, practice-based holistic teaching using imagined vocational practice can help connect STEM subjects with practical examples and cases from the students' future vocation. However VET colleges often lack the appropriate settings to support this (Andersen et.al., 2022). Creating the necessary setting for practice-based holistic teaching requires strong collaboration between vocational teachers and teachers in STEM subjects, where teachers can plan lessons together and share a mutual interest in establishing collaboration.

This requires different collaborative conditions, which involve scheduling that makes this possible, providing the necessary physical settings, and ultimately requiring financial and managerial prioritization. When teachers collaborate and have cross-disciplinary dialogue, it can support students' perception that their knowledge and skills in STEM subjects are important for their future vocational practice. When a STEM teacher can incorporate real-world examples and convey cases representing practice or give students concrete and hands-on experiences through tasks, many students find a sense of purpose in STEM subjects, contributing to an increased understanding and practical mastery of tasks and processes they encounter in the more practical areas of their education.

Many STEM teachers neither have substantial experience in nor knowledge of the vocation their students are training for. Often, STEM teachers must teach across various vocational programs with vastly different practical expertise, thus needing to connect their teaching to various vocations. These teaching conditions significantly limit their ability to conduct practice-

based holistic teaching. Greater knowledge of the subjects, along with opportunities to teach within fewer types of vocational programs, could potentially create better conditions for practice-based holistic teaching, possibly through increased collaboration with vocational teachers across the different programs (Andersen et.al., 2022;2024).

An interdisciplinary collaboration between STEM teachers and vocational teachers can potentially enhance the practice-based holistic teaching and students' perception of the importance and applicability of STEM subjects. Such collaboration can bridge the gap between subjects like physics and the practical skills students develop and practice in the vocational subjects (Margot & Kettler, 2019).

It is essential that there is a continuous interdisciplinary dialogue among teachers. Practice-based holistic teaching can be enhanced, for instance, by using repetitions of the same examples across STEM teaching and teaching in practical skills and subjects (Andersen et.al., 2024). This strengthening can also occur when teachers concretely participate in each other's lessons and gain cross-disciplinary insights that way. However, to establish interdisciplinary collaboration, it is crucial that teachers have both the conditions and the enthusiasm and engagement in the cooperation, allowing them to continuously discuss students' educational progress.

The desire for and the structural possibilities for continuous coordination allow teachers to reference the same examples across STEM and practical subjects, providing students with the experience that STEM subjects are relevant for solving tasks in workshops, in the forest, in the kitchen, and in the care unit. In other words, practice-based holistic STEM teaching requires joint planning efforts where teachers in the different subject areas can identify opportunities to integrate parts of the subjects into cohesive units.

Such ongoing dialogue can give the STEM teacher the opportunity to organize and adapt the teaching process to the topics and activities students encounter in the practical parts of their education. These continuous adjustments can provide students with a holistic understanding that the different subjects complement each other.

Conclusion

Practice-based, holistic STEM teaching in vocational education and training can increase students' motivation and learning when STEM subjects are combined with vocational practice. The article distinguishes between two ways of incorporating practice into teaching: Imagined vocational practice and experienced vocational practice. Imagined vocational practice might involve the inclusion of cases and examples where students are invited to imagine practical applications of theoretical knowledge without being physically present in a vocational setting. Experienced vocational practice gives students concrete experiences with vocational work situations, thus requiring less of their imagination. Experienced vocational practice has the potential to increase and strengthen motivation in multiple student groups. This both applies to students who have no former practice experience with the vocation. It also applies to students who are not so capable of imagining a practice that becomes too abstract for them. Last but not least it applies to students who want to work in practice with their future vocation as much as possible.

Additionally, the article posits that teaching can be optimally planned with a focus on

experienced vocational practice during students' initial training period, and only later include imagined practice. This approach benefits students who have had negative experiences with STEM subjects in previous schooling, as they can feel more competent in STEM subjects when applied in a context where they are invited to experience a concrete physical practice. At the same time, this meets many students' expectations for vocational education, which is often based on a desire to work with and in a tangible vocational context.

The article emphasizes the importance of interdisciplinary collaboration between STEM teachers and vocational teachers. This collaboration is crucial for creating relevant and meaningful STEM teaching that can contribute to increased student engagement and a deeper understanding of STEM subjects.

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